U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-100464

Characterization of Vegetation and Drainage in Strip Mined Land Utilizing Remote Sensing Techniques

Missouri Univ -Rolla

Prepared for

Industrial Environmental Research Lab -Cincinnati, OH

Aug 79

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/7-79-194
August 1979

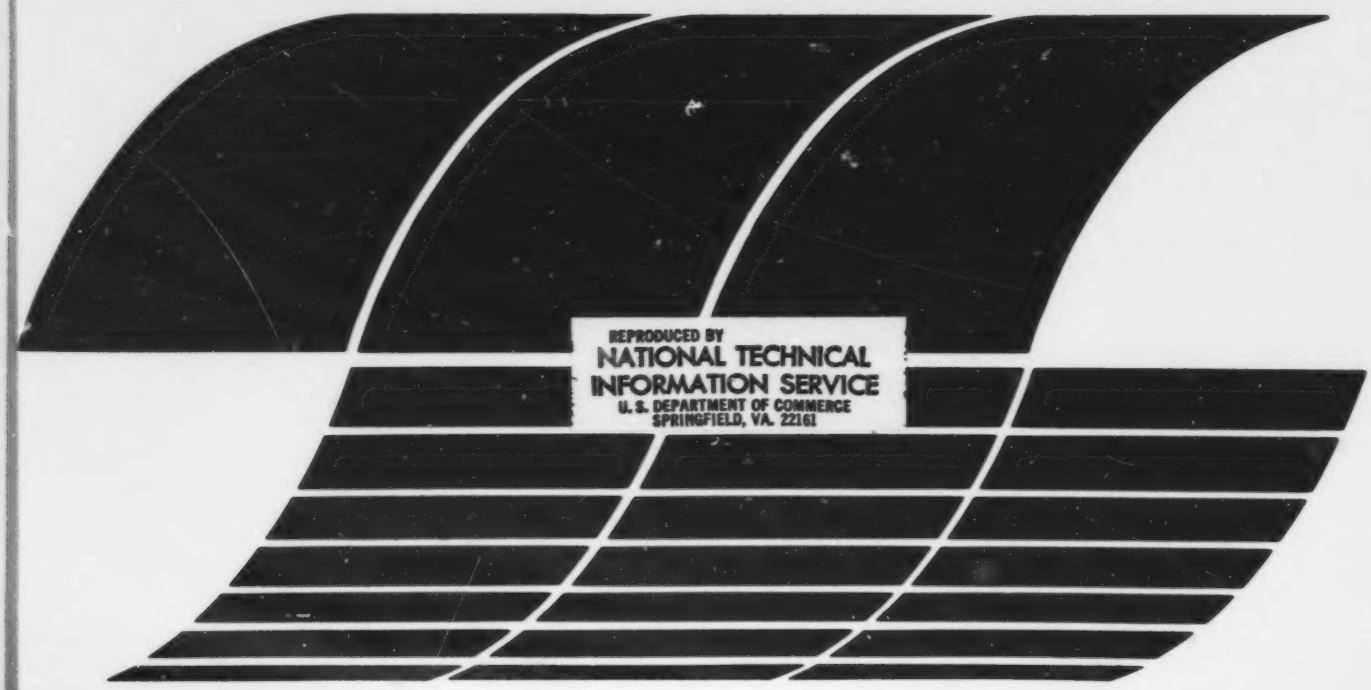
Research and Development

PB80-100464

EPA

Characterization of Vegetation and Drainage in Strip Mined Land Utilizing Remote Sensing Techniques

Interagency Energy/Environment R&D Program Report



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-79-194		

4. TITLE AND SUBTITLE	5. REPORT DATE
Characterization of Vegetation and Drainage in Strip Mined Land Utilizing Remote Sensing Techniques	August 1979 issuing date
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
C. Johannsen, T. Barney, A. Coble, J. Carrel, W. McFarland, and D. Barr	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
University of Missouri-Rolla Rolla, Missouri 65401	1NE623
	11. CONTRACT/GRANT NO. SEA-CR IAG 684-15-20

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Industrial Environmental Research Laboratory Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268	final
	14. SPONSORING AGENCY CODE 600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Research conducted during this project has utilized remote sensing images and data to study surface vegetation identification, vegetation biomass and drainage patterns on coal strip mined land. Study sites were located in Boone, Randolph and Macon counties in central Missouri. This report presents the results of surface vegetation and drainage analyses of those sites and methodologies used for accurate, timely and useful applications of remotely gathered data for monitoring coal surface mining reclamation activities. A computer based technique was developed for assessing the extent of reestablished vegetation on the study sites. Color infrared aerial photographs obtained over the sites were scanned and converted into digital outputs. Classification accuracy was established by comparing the results to known ground cover quantified by quadrat and area metering methods. The methodology subsequently developed offers a reasonable compromise between manual photo interpretation and automatic machine processing strategies for assessment of vegetative ground cover on strip mined lands from remotely sensed data. Vegetative cover was verified in randomly located quadrats on the mined sites. Reference standards were thus established for the analysis and classification made by both area metering and digital image analysis methods. Although computer system is more versatile, both methods are rapid and highly (85-90%) accurate. Nine additional mine sites were studied for further comparison of the effects of plant productivity, species diversity and density to the remotely sensed classification.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Coal Surface Mining Remote Sensing Drainage Vegetation	Missouri Reclamation Color infrared Computer Aerial photo	13b

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to the Public	Unclassified	82
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	PCA05/HF/A01

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979-657-060/5388

EPA-600/7-79-194
August 1979

CHARACTERIZATION OF VEGETATION AND DRAINAGE IN STRIP MINED LAND UTILIZING REMOTE SENSING TECHNIQUES

by

Chris J. Johannsen, Agronomy
Terry W. Barney, Agronomy
A. Dale Coble, Agronomy
James E. Carrel, Biological Sciences
William McFarland, Bioengineering Programs
University of Missouri-Columbia
Columbia, Missouri 65211

and

David J. Barr, Mining, Petroleum and Geological Engineering
University of Missouri-Rolla
Rolla, Missouri 65401

SEA-CR IAG No. 684-15-20

Project Officer

Ronald D. Hill
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

This study was conducted in cooperation with the Science and Education Administration, Cooperative Research, USDA, Washington, DC 20250

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommedation for use.

The views and conclusions contained in this report are those of the authors and should not be interpreted as representing the official policies or recommendations of the Science and Education Administration-Cooperative Research, U. S. Department of Agriculture.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the results of surface vegetation and drainage analyses of those sites and the methodologies used for accurate, timely and useful applications of remotely gathered data for monitoring coal surface mining reclamation activities.

Further information may be obtained from the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Research conducted during this project has utilized remote sensing images and data to study surface vegetation identification, vegetation biomass and drainage patterns on coal strip mined land. Study sites were located in Boone, Randolph and Macon counties in central Missouri. This report presents the results of surface vegetation and drainage analyses of those sites and the methodologies used for accurate, timely and useful applications of remotely gathered data for monitoring coal surface mining reclamation activities.

A computer based technique was developed for assessing the extent of reestablished vegetation on the study sites. Color infrared aerial photographs obtained over the sites were scanned and converted into digital outputs. Classification accuracy was established by comparing the results to known ground cover quantified by quadrat and area metering methods. The methodology subsequently developed offers a reasonable compromise between manual photo interpretation and automatic machine processing strategies for assessment of vegetative ground cover on strip mined lands from remotely sensed data.

Vegetative cover was verified in randomly located quadrats on the mined sites. Reference standards were thus established for the analysis and classification made by both area metering and digital image analysis methods. Although the computer system is more versatile, both methods are rapid and highly (85-90%) accurate. Nine additional mine sites were studied for further comparison of the effects of plant productivity, species diversity and density to the remotely sensed classification.

Aerial photography used in the vegetation classification and the computer ground cover analysis plus additional photography provided the basis for analyzing pre- and post-mining drainage features. Pattern, density and orientation of erosional features was analyzed and 1:24,000 scale maps were produced. The alteration from a pre-mined naturally dendritic drainage pattern to a post-mined rectangular pattern has caused several observed problems. The change in terrain surface creates a higher potential for erosion. The initial post-graded convex slopes have very low drainage densities. This leads to a very high likelihood of erosion and often results in excessive densities following heavy precipitation. Sediment retention and plant establishment would profit greatly from a change to concave slopes. Many sedimentation ponds could also be eliminated. Constructing a random drainage pattern of the proper density would be a substantial asset in reducing sediment outflow from the mined site.

This report was submitted in fulfillment of Contract No. 684-15-20 by the University of Missouri in cooperation with the Science and Education Administration, Cooperative Research Unit, USDA under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from July 1, 1976 to September 30, 1978 and was completed as of December 31, 1978.

TABLE OF CONTENTS

		Page
	ABSTRACT	iv
	FIGURES	viii
	TABLES	x
	ACKNOWLEDGMENTS	xi
I.	INTRODUCTION	1
II.	CONCLUSIONS	3
III.	RECOMMENDATIONS	5
IV.	SURFACE OBSERVATIONS	7
	METHODS AND PROCEDURES	7
	Vegetative Cover Determination	7
	Vegetation Identification	11
	Determination of Species Diversity	11
	Importance Value Determination	12
	Determination of Stability	12
	RESULTS AND DISCUSSION	12
	Vegetative Cover Determination	12
	Vegetation Identification	18
	Species Diversity	19
	Productivity	23
V.	COMPUTER ANALYSIS	27
	METHODS AND PROCEDURES	27
	Digital Image Generation	27
	Methodology Development	28
	Technique Overview	29
	Technique Evaluation	29

Preceding page blank

TABLE OF CONTENTS (continued)

		Page
	The Interactive Gray Level Slicing Technique	35
	Analysis procedure	35
	Scanning and display	35
	Delineation of mine site boundary	41
	Interactive gray level slicing	41
	Classification and print-out	41
	Accommodating Input Variables	41
	RESULTS AND DISCUSSION	44
	Precision of Analysis	44
	Classification Accuracy	45
	Seasonal Variations	47
VI.	EROSION AND DRAINAGE ANALYSIS	49
	METHODS AND PROCEDURES	49
	Summary of Appropriate Theory and Literature	49
	Drainage Map Preparation	51
	Evaluation of Slope Geometry	52
	ANALYSIS PROCEDURES	52
	Drainage Density	52
	Drainageway Orientation	53
	RESULTS AND DISCUSSION	60
	Accuracy Standards	60
	Mined Land Landscaping	60
	Methods	60
	Study Site Observations	62
	Applications	63
VII.	INFORMATION PROGRAM	67
VIII.	REFERENCES	68

FIGURES

Number		Page
1.	Aerial photograph composite showing study sites in Strip Mine 1 located in Boone County, Missouri	8
2.	Aerial photograph composite showing study sites in Strip Mine 2 located in Randolph County, Missouri	9
3.	Aerial photograph composite showing study sites in Strip Mine 3 located in Macon County, Missouri	10
4.	Percent cover verification employing aerial photography and ground level techniqes	13
5.	Number of species in vegetation types in pre-law and post-law mine sites	20
6.	Importance of vegetation types in pre-law and post-law mine sites	20
7.	Increase in woody plants with age of surface coal mines	21
8.	Importance value curves for nine mine sites	21
9.	Species-area curves for nine Missouri strip mine sites reseeded to forage species	22
10.	Plant species diversity in reseeded surface mines as a function of time	22
11.	Productivity of vegetation in nine strip mine sites	25
12.	Annual change in plant productivity as a function of time	26
13.	Relationship between diversity and stability in reseeded strip mines	26
14.	Digital image histogram showing general trends in gray level response distribution for bare soil, vegetation and water	30

FIGURES (continued)

Number		Page
15.	Technique evaluation results for automatic gray level slicing routine	.32
16.	Technique evaluation results for supervised training field routine	.33
17.	Technique evaluation results for interactive gray level slicing routine	.34
18.	Interactive gray level slicing flow diagram	.36
19.	A digital image of post-law site 2 at Strip Mine 2 as displayed on the black and white interactive digital display	.37
20.	Digital display of gray level slice representing water at post-law site 2, Strip Mine 2	.38
21.	Digital display of gray level slice representing vegetation at post-law site 2, Strip Mine 2	.39
22.	Line Printer output showing tabulated summary of picture points for each class and acreage conversion	.40
23.	Line Printer output upon which the individual classes have been delineated	.42
24.	Slope profile shape for four different types of slopes	.50
25.	Pre-mining drainage patterns of Strip Mine 1, Boone County, Missouri	.54
26.	Post-mining drainage patters of Strip Mine 1, Boone County, Missouri	.55
27.	Pre-mining drainage patterns of Strip Mine 2, Randolph County, Missouri	.56
28.	Post-mining drainage patterns of Strip Mine 2, Randolph County, Missouri	.57
29.	Drainage map showing early (pre-1950) mining plus natural drainage patterns for Strip Mine 3, Macon County, Missouri	.58
30.	Post-mining drainage patterns of Strip Mine 3, Macon County, Missouri	.59
31.	A random drainage pattern with A_0 and A_1 defined by sub-unit drainage dividers	.64

TABLES

Number		Page
1.	Cover Characteristics of a Pre-law and Post-law Site at Strip Mine 1	13
2.	Vascular Plants in Three Missouri Strip Mines	14
3.	Vegetative Species Composition in Pre-law Site 2 at Strip Mine 3 Seeded to Pasture	18
4.	1977 Vegetation Production by Vegetative Group of Three Missouri Strip Mines in Different Stages of Reclamation	24
5.	1978 Vegetative Production by Vegetative Group of Three Missouri Strip Mines in Different Stages of Reclamation	24
6.	Preliminary Comparison of Overall Classification Accuracy Between Interactive Gray Level Slicing and Training Field Techniques	31
7.	Precision Evaluation of Interactive Gray Level Thresholding, Pre-law Site 1, Strip Mine 1	44
8.	Accuracy of Interactive Gray Level Slicing for Multiple Scans of Pre-law Site 1, Strip Mine 1	45
9.	Classification Accuracy Evaluations for Additional Pre- and Post-law Sites Utilizing the Interactive Gray Level Slicing Technique	46
10.	Seasonal Acreage Comparison for Post-law Site 3, Strip Mine 2	47
11.	Seasonal Acreage Comparison for Post-law Site 2, Strip Mine 1	47
12.	Seasonal Acreage Comparison for Post-law Site 2, Strip Mine 2	48
13.	A Summary of Pre-mined and Post-mined Drainage Density Shown in Figures 25-30	52
14.	Relationship of Oth Order Watershed Area and Drainage Density To Watershed Parameters	61

ACKNOWLEDGMENTS

Work reported in this publication was financed by funds from the Environmental Protection Agency as provided through the USDA Science and Education Administration - Cooperative Research to the Missouri Agricultural Experiment Station. The work was performed by faculty and staff from four different University Departments within three Colleges located at two campuses of the University of Missouri. The Department of Agronomy (College of Agriculture) was the coordinating department with Mr. Terry Barney, Research Specialist, providing major coordination in all phases of the work during the first year. Responsibilities also included arrangement for remote sensing data collection, analysis and interpretation. Mr. Dale Coble, Research Specialist, performed the coordination role during the second year with assistance from Mr. Barney.

Dr. James Carrel, Associate Professor of Biological Sciences (College of Arts and Sciences) was responsible for the ground observations, vegetation identification and analysis of ground cover at the mine sites. He was assisted by a number of students, but especially by Mr. Steve Weems and Ms. Leslie Bouchard, Graduate Research Assistants, with the field work and laboratory analysis.

Dr. William McFarland, Assistant Professor of Electrical Engineering (Bioengineering Programs, College of Engineering), was responsible for the computer analysis phases. He was greatly assisted by Tachpong Hotrabhavananda, Graduate Research Assistant, who performed computer programming and software generation during the digitizing and analysis of the aerial photography.

Dr. David J. Barr, Professor of Geological Engineering (Department of Mining, Petroleum and Geological Engineering, School of Mining, UMR) was responsible for the hydrology and drainage research phase. He was primarily assisted by C. Dale Elifrits and Shara McBee in the interpretation and mapping work.

The cooperation of the coal companies operating in Missouri is greatly appreciated. The Missouri Land Reclamation Commission and the Missouri Land Reclamation staff of the Missouri Department of Natural Resources assisted the investigators in numerous ways.

Many University administration staff needed to be consulted and informed on the progress of the work reported herein. The secretarial and typing skills of Ms. Pat Cook and Becky Manford are acknowledged. Samuel R. Aldrich, University of Illinois, served as the Project Officer of this research and

Eilif V. Miller coordinated the effort for the Science and Education Administration, Cooperative Research Unit, USDA. It was my pleasure to work with all of the talent mentioned above as Principal Investigator.

Chris J. Johannsen
Professor of Agronomy
University of Missouri-Columbia

INTRODUCTION

Current estimates of coal strip mined land in Missouri approach 76,000 acres (Young, 1978). This land is dispersed throughout thirty counties in North Central and Western Missouri with four major and fifteen minor companies presently engaged in surface coal mining operations. The Missouri Land Reclamation Commission issues permits for over 2,000 acres each year. This figure is steadily increasing and may take a sizable jump if plans for establishing two coal gasification plants are realized.

Missouri ranks 9th among states in total coal reserves (Robertson, 1971). There are thirty-one billion tons of coal that have been located and inventoried with an additionally estimated 18 billion tons not verified by test drilling.

The 67,000 acres of land mined prior to the 1972 Missouri Reclamation Law are in varying stages of reclamation with most of the acreage needing more vegetative cover. This project was planned to assist with developing monitoring and inventorying techniques that could be used by the coal companies and the Missouri Land Reclamation staff. A new mining law was passed by the 1978 Missouri Legislature which incorporated the required guidelines of the Federal Surface Mining Control and Reclamation Act of 1977.

The pre-law sites named in this study refer to sites mined prior to 1972 while the post-law mine sites were mined after that date. This study sought to: (1) characterize the amount of vegetation that had been established on both pre-law and post-law sites, (2) characterize the type of drainage patterns resulting from the different mining conditions, (3) develop computer analysis techniques that could extend the surface characterization of vegetation and soil and water over a larger area, and (4) relay the information derived from the studies to individuals, groups and organizations that can utilize them through an Extension Information Program.

Remote sensing data in the form of aerial photography (primarily color infrared and black and white) were collected over the study sites at different times of the growing season. The photography was used to locate the sites for vegetation identification, to measure the areal extent of vegetation areas, to classify the land cover categories in the computer analysis and to develop drainage maps for each mine site.

The principal investigator and a research specialist coordinated the work of the investigators and graduate students by holding project seminars, arranging photographic missions and remote sensing analyses and communicating

between the users and researchers.

The study sites in this project are identified by county location and number which is a cooperative arrangement between the coal companies, the University of Missouri and the Missouri Land Reclamation Commission. It was felt that results, pro and con, to the interests of each group could be better expressed if county and numerical locations were used. The study sites were located in Boone County designated as Strip Mine 1 (Figure 1), in Randolph County designated as Strip Mine 2 (Figure 2), and Macon County which was designated as Strip Mine 3 (Figure 3). There are pre-law and post-law sites in each study area. There were three main post-law sites with seven additional sites in the mine areas used for the surface observation studies.

Results from the work reported in this publication were made available in preliminary form to the cooperating coal companies and the Missouri Land Reclamation Commission. Meetings were held with professionals from many organizations concerning the impacts of both strip mining and reclamation efforts on local communities. A workshop was also held with the members of the Missouri Mining Industry Council on applying the research results to their work.

The most important result that researchers can report is the acceptance and use of their efforts. Upon reviewing the results of this project, the Missouri Land Reclamation Commission requested and received color infrared aerial photography from the Environmental Protection Agency over all surface mined lands of Missouri. Arrangements have been made with the University of Missouri to provide computer output maps from the photography showing revegetation process and extent of the mined areas utilizing the techniques developed under this contract.

CONCLUSIONS

SURFACE OBSERVATIONS

1. All sites are dominated by forage species.

2. The topsoiled site has more weedy, volunteer species than sites covered with spoil material.

3. Grading in post-law mines promotes plant species establishment, diversity, productivity and stability.

4. Unless properly managed, strip mine succession tends toward a woody condition.

5. Productivity of most mines increases with age to agronomically acceptable levels.

6. Topsoiled mines are not more productive than ones of comparable age covered with spoil material.

7. Topsoiling may offer some problems as well as solutions for establishment of permanent pasture on surface mines in Missouri.

COMPUTER ANALYSIS

1. Digital image processing of color infrared aerial photography can be effectively utilized in the classification of pre-law and post-law coal strip mine sites into three basic categories: bare soil, vegetation and water. Spatial estimates of each class can be compiled quickly and accurately.

2. This methodology is not reliable or cost effective for measurements of species composition or plant productivity. The methodology was designed exclusively for measuring the areal extent of ground cover on surface mines.

3. Varying scales and film formats of CIR imagery can be accommodated by the computer based technique developed.

4. Periodic monitoring of coal strip mines for change detection with regard to extent of revegetation is feasible.

5. Digital image analysis of conventional CIR aerial photography offers a reasonable trade-off between the high degree of classification accuracy associated with manual interpretation methodologies and the temporal efficiency of machine processing.

EROSION AND DRAINAGE ANALYSIS

1. Extensive erosion will occur in unreclaimed and reclaimed mine areas until the necessary drainage pattern and density is constructed naturally or artificially thus bringing the mine site more nearly into equillibrium with the surrounding unmined area.

2. Mining and subsequent reclamation create terrain surfaces that require greater drainage densities than exist prior to mining for maximum erosion control.

3. Maximum erosion control dictates the need for use of concave slopes wherever possible.

4. Observed reclamation practices create high potentials for erosion due to initial low drainage densities and use of convex slopes.

5. Some disruption of natural flow with sedimentation ponds is advisable to reduce sediment transport off the mine site. However, a designed drainage system would reduce the number of ponds needed and extend the usable life of those constructed.

6. A designed drainage system lends itself to the more uniform distribution of water over the mine landscape thus enhancing revegetation efforts.

RECOMMENDATIONS

SURFACE OBSERVATIONS

1. Pre-law surface mines that are undergoing rapid annual increases in extent of vegetative cover should be left relatively undisturbed and should be studied for several years until percent cover stabilizes.

2. Controlled cropping by mowing or grazing of pastures in reclaimed surface mines should be performed every two years or so in order to retard invasion by successional, woody plant species and to avoid replacement of forage species. Pasture maintenance activities not only would benefit vegetated areas, but if properly timed could enhance covering of barren remnants, particularly steep slopes in pre-law mines, with forage species.

3. Controlled cropping and selective reseeding of forages should also be performed to promote and to maintain high levels of plant productivity (>200 g/m) in mineland pastures.

4. One or two additional years of study are needed to fully document annual changes in vegetative cover, species composition, and particularly productivity of pastures in selected Missouri surface mines.

COMPUTER ANALYSIS

1. Additional study is needed to document, in a statistically valid manner, the accuracy of individual digital picture point classifications. Although overall accuracies are good, further documentation will be required for more detailed, site specific analyses and implementation of routine monitoring schemes.

2. Techniques for interfacing digitized aerial photography data with other mine site data in computerized data base format should be pursued.

3. Randomly selected mine sites from other areas of the United States should be evaluated to test the flexibility and universality of this assessment technique.

EROSION AND DRAINAGE ANALYSIS

1. This study indicates that significant changes in drainage density, drainage orientation and slope shape occur during the reclamation process and these changes increase the potential for severe initial erosion. A detailed cost/benefit study should be implemented that would include:

   a. Field experimentation with the mechanics of mine land "sculpturing" to test drainage density, drainage orientation and slope shape concepts.

   b. Cost determinations for proper drainage channel design and construction.

   c. Field measurements of drainage equation variables.

   d. Determination of the optimum placement of detention ponds and their effects on revegetation success within a designed drainage system.

   e. Comparisons of sediment production and erosion control costs between a study site and a standard practice site.

SURFACE OBSERVATIONS

by

Dr. James E. Carrel and Steve Weems 1/

METHODS AND PROCEDURES

Surface observations are a verification of what is being observed by remote sensing media. The methods vary depending upon the type of remote sensing measurements, type of terrain, type and amount of surface cover, personnel and equipment available, accessibility to the study site and other related factors.

Study sites were located in pre-law and post-law minelands at three different mining operations (Figures 1, 2 and 3). Measurements of species identification and plant vigor throughout the growing season were obtained on the pre-law minelands to provide needed information for the success of species adaptation on different mined spoils which is useful in post-law mining operations.

In this project, the surface observations were designed to provide: (1) a detailed species composition in the different mine land conditions; (2) a measure of the vegetative productivity of each study area; (3) a set of reference standards for use in the computer image analysis. Further, aerial photography techniques of collecting surface observations were also used to compare with accuracies of ground level measurements.

Vegetative Cover Determination

Large scale (1:6,000) vertical aerial photographs of a surface mine were printed either in black and white or color. The scale was verified in two ways. In the laboratory, large (10^3m) distances between features indicated on U.S.G.S. topographic maps (1:24,000) were compared with those visible in the photographs. In the field, small (10^2m) distances measured with a tape were compared with those visible in the photographs.

1/ Associate Professor of Biological Sciences and Graduate Research Assistant in Biological Sciences, University of Missouri-Columbia

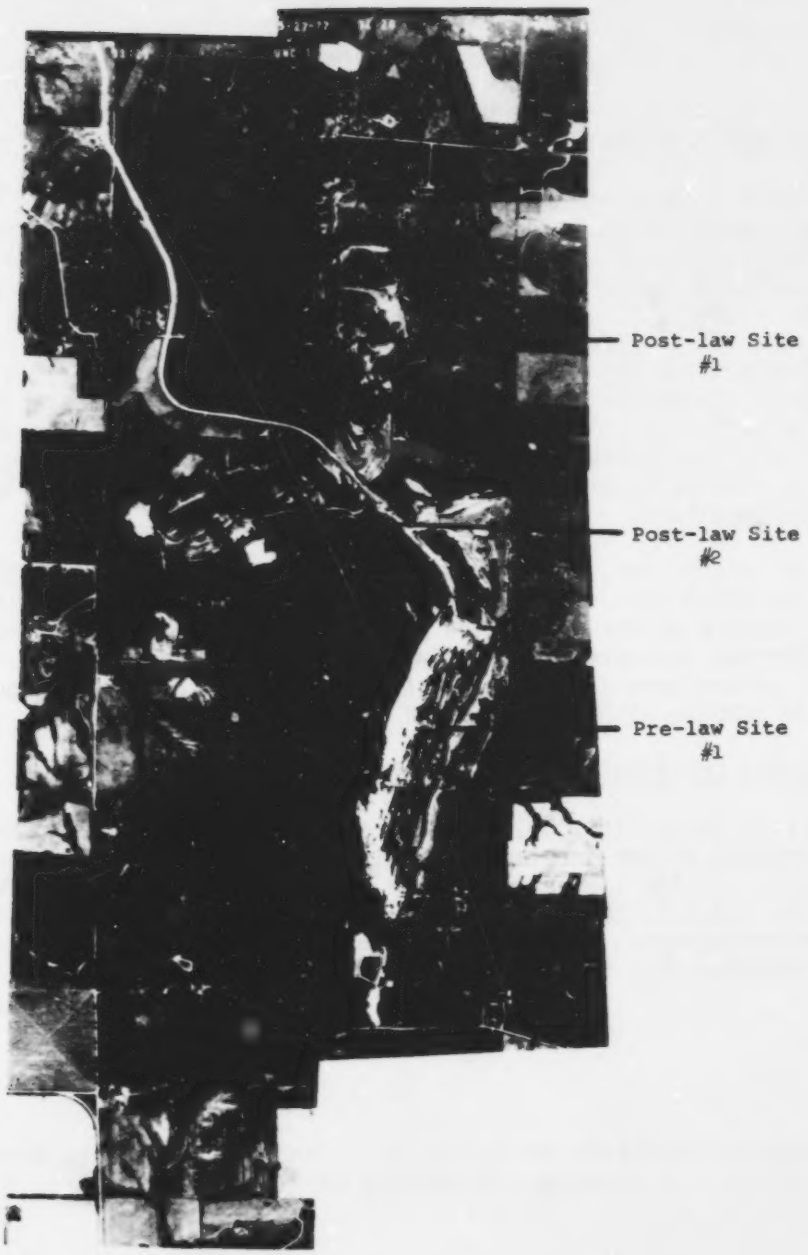


Figure 1. Aerial photograph composite showing study sites in Strip Mine 1 located in Boone County, Missouri.

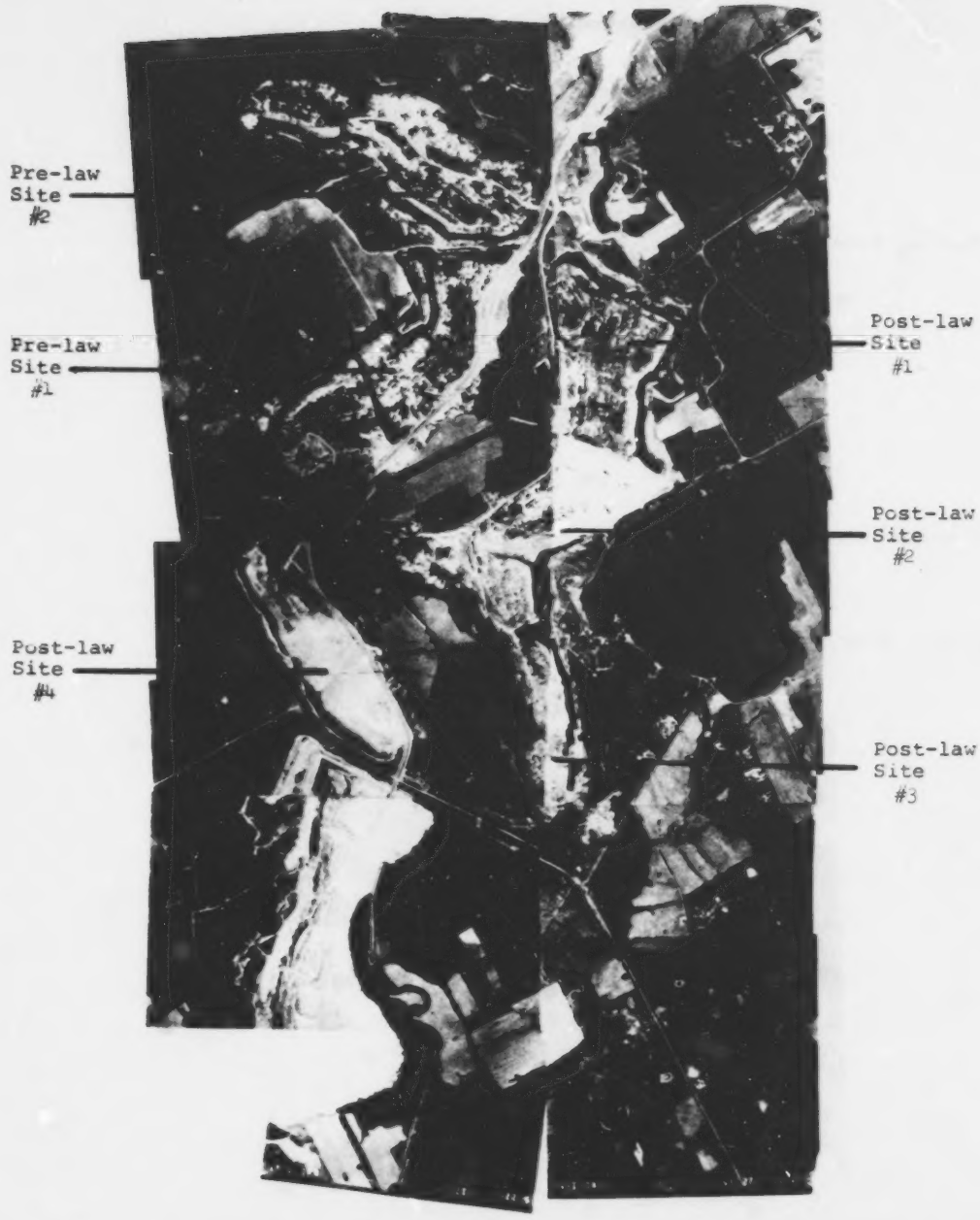


Figure 2. Aerial photograph composite showing study sites in Strip Mine 2 located in Randolph County, Missouri.

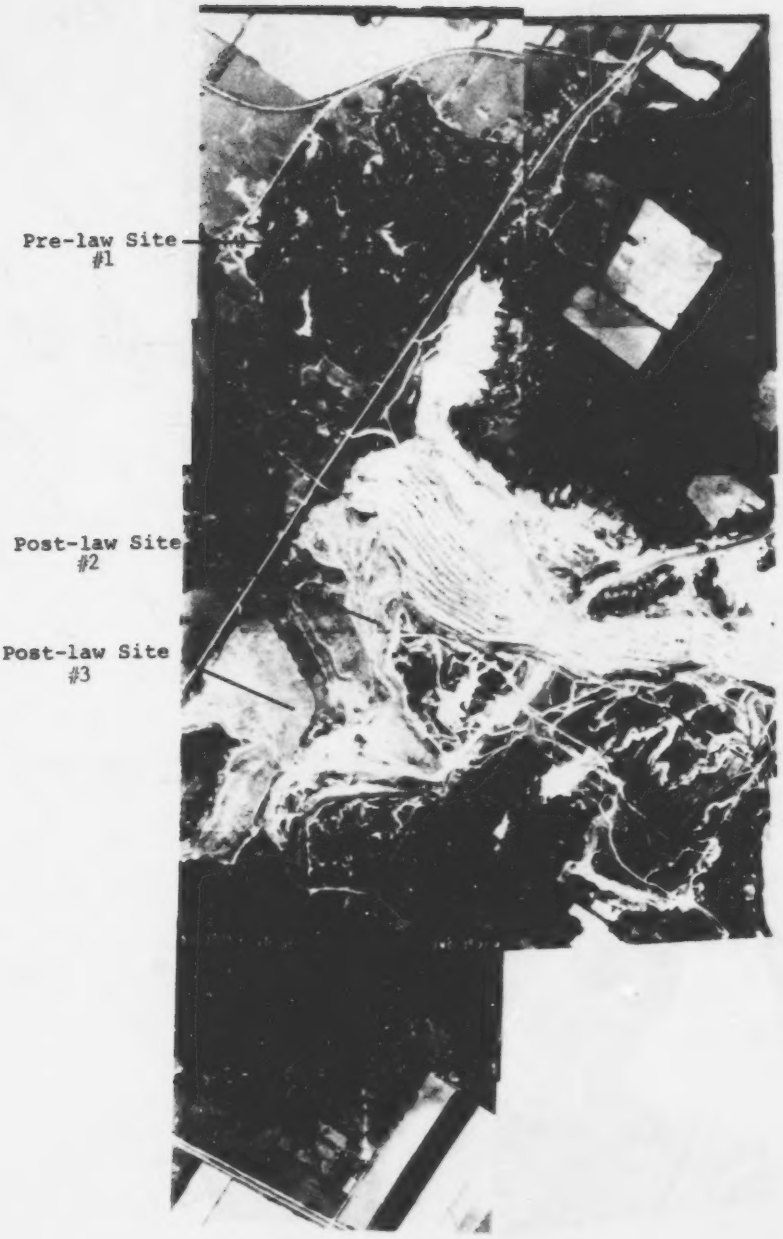


Figure 3. Aerial photograph composite showing study sites in Strip Mine 3 located in Macon County, Missouri.

Cover classification in a surface mine proceeded in a step-wise fashion. First, the perimeter of a mineland was marked on the photographic print. A silhouette of the entire mine was made by inking a clear plastic overlay. In a similar fashion transparent overlays of the total vegetation, woody vegetation and water were prepared. Darkened areas (mm^2) were measured individually using a leaf area meter (Carrel et al., 1977) and their real areas were calculated by multiplication by the verified scale factor. The areas occupied by bare soil or herbaceous vegetation were calculated by subtraction. Finally, relative abundance of the different cover classes was determined.

Vegetation Identification

Vegetation growing in surface mines was separated into two categories: woody and herbaceous. Trees and shrubs have a different texture and color in aerial photographs than do grasses and legumes,so the two classes are readily differentiated by a trained observer. In minelands artificially seeded with forage species, woody plants are rare and individually identifiable.

Nine mine sites in Central Missouri reseeded with a standard mixture of tall fescue and legumes were studied. Three pre-law sites had a ridge and valley topography, whereas six post-law sites were graded to a gently rolling terrain. Only one post-law site had been topsoiled before it was planted with forages. Plant species composition and abundance in surface mines were measured by quadrat sampling along transects. Quadrats ($0.5m^2$) were established at 30m intervals along parallel transects spaced 200m apart across a mine. The above-ground plant biomass was clipped in late summer and segregated by species for dry weight determination. Ground cover was quantified by quadrat and area-metering methods. Samples were obtained in September-October 1977 and 1978. Data for plant species composition, abundance, and productivity were calculated using standard ecological formulas as follows:

Determination of Species Diversity--

a) Species richness = absolute # of species = N

b) Gleason's Index of Diversity

$d = \frac{N}{\ln A}$ where:

N = total # of species

A = Area of study site

d = constant used to measure relative diversity

Importance Value Determination--

$$\text{Absolute frequency of species} = \frac{\#\text{quadrats the species occurs in}}{\#\text{ quadrats sampled}}$$

$$\text{Precent frequency} = \frac{\text{Absolute frequency}}{\text{Cummulative frequency of all species}} \times 100$$

Dry wt. of species = Cummulative wt. of quadrats by species X 2 g/m^2

$$\text{Percent Biomass} = \frac{\text{Cummulative wt. (a species)}}{\text{Cummulative wt. (all species)}} \times 100$$

Importance Value = Percent frequency + Percent Biomass (Scale of 200)

(Adapted from Curtis and Cottham, 1956)

Determination of Stability--

The flux in primary productivity (g/m^2) from one growing season to the next is one measure of stability for any given habitat. Plants were harvested at the end of two successive growing seasons and species biomass determined. Calculations were made as follows:

$\Delta P_n^{n+1} = P_n - P_{(n+1)}$ where:

P n = productivity (g/m^2 of a mine for the following year.

P (n+1) = productivity (g/m^2) of a mine for the following year.

ΔP_n^{n+1} = the change in productivity, either (+) or (-) from one year to the next.

RESULTS AND DISCUSSION

Vegetative Cover Determination

Vegetative cover was determined for the different mine sites mined under pre-law and post-law regulatory conditions. The findings of Strip Mine 1 are typical of the conditions found at other locations (See Table 1). The pre-law site contains 20.8% vegetative cover vs 48.4% for the post-law site. The woody plants make up 0.4% and 0.1% of the vegetation area indicating that woody species are not major invaders in Central Missouri mines under these conditions.

TABLE 1. COVER CHARACTERISTICS OF A PRE-LAW AND POST-LAW SITE AT STRIP MINE 1

	Pre-law Site		
		Cover (%)	
	Area (m^2)	Total	Land
Vegetation - Herbaceous	25,679	20.4	21.8
Woody	547	0.4	0.5
Subtotal	26,226	20.8	22.3
Bare Soil	91,517	72.7	77.7
Land	117,743	93.5	100.0
Water	8,173	6.5	--
Total	125,916	100.0	--
	Post-law Site		
Vegetation - Herbaceous	117,830	48.3	52.6
Woody	212	0.1	0.1
Subtotal	118,042	48.4	52.7
Bare Soil	105,042	43.4	47.3
Land	223,849	91.8	100.0
Water	20,005	8.2	--
Total	243,854	100.0	--

Two methods of verifying vegetative cover were used: ground level and aerial photography. A comparison of the two methods (Figure 4) shows a significant correlation ($r = 0.95$, $p<.01$) between the two methods (Carrel et al., 1978a). This indicates that the low altitude aerial photography approach is very acceptable for obtaining surface observations over mined lands for differentiating vegetation, soil, and water.

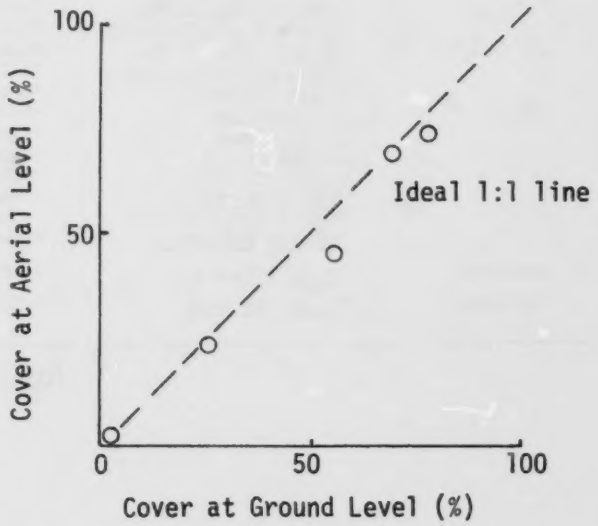


Figure 4. Percent cover verification employing aerial photography and ground level techniques.

TABLE 2. VASCULAR PLANTS IN THREE MISSOURI STRIP MINES

CLASS	FAMILY	SPECIES	COMMON NAME	MINE
Gymnospermae	Cupressaceae	Juniperus virginiana	Red Cedar	A
	Pinaceae	Pinus echinata	Short-leaf Pine	A
		Pinus sylvestris	Pine	A
Angiospermae				
Subclass				
Monocotyledoneae	Cyperaceae	Carex brevoir	Sedge	A
		Carex vulpinoides	Sedge	ABC
		Scirpus lineatus	Bulrush	A
	Gramineae	Agrostis hiemalis	Hairgrass	AB
		Alopecurus carolinianus	Foxtail	A
		Andropogon virginicus	Broomsedge	A
		Aristida lonispica	3-awn Grass	A
		Aristida oligantha	3-awn Grass	ABC
		Avena sativa	Oats	A
		Bromus inermus	Smooth Brome	A
		Bromus japonicus	Japanese Chess	ABC
		Bromus racemosus	Cheat/Chess	AB
		Dactylis glomeratus	Orchard Grass	ABC
		Echinoclca muricata	Barnyard Grass	ABC
		Elymus riparus	Wild Rye	A
		Elymus virginicus	Rye	A
		Festuca elatior	Meadow Fescue	ABC
		Festuca octoflora	Six Weeks Fescue	A
		Festuca paradoxa	Fescue	B
		Hordeum pusillum	Little Barley	AB
		Lolium perene	Perennial Ryegrass	A
		Panicum capillare	Switch Grass	C
		Panicum depauperatum	Fall Panic	A
		Panicum dichotomiflorum	Fall Panic	ABC
		Panicum lanuginosum	Fall Panic	BC
		Panicum linearifolium	Fall Panic	C
		Phleum pratense	Timothy	ABC
		Poa compressa	Bluegrass	A
		Poa pratensis	Bluegrass	A
		Setaria glauca	Foxtail	ABC
		Setaria viridis	Yellow Foxtail	BC
		Sorghum halapense	Johnson Grass	A
		Tridens flavus	Purpletop	A
		Triticum aestivalis	Wheat	BC
	Juncaceae	Juncus tenuis	Rush	AB
	Liliaceae	Allium canadense	Wild Garlic	A

(continued)

TABLE 2. (continued)

CLASS	FAMILY	SPECIES	COMMON NAME	MINE
Angiospermae				
Subclass				
Dictotyledoneae	Acanthaceae	Ruellia humilis	Wild Petunia	A
	Aceraceae	Acer saccharinum	Sugar Maple	A
	Anacardaceae	Rhus glabra	Smooth Sumac	AC
		Rhus radicans	Poison Ivy	A
	Apocynaceae	Apocynum cannabinum	Indian Hemp	AB
		Apocynum sibiricum	Indian Hemp	A
	Asclepiadaceae	Asclepias hirtella	Milkweed	B
		Asclepias incarnata	Swamp Milkweed	C
		Asclepias syriaca	Milkweed	AC
	Betulaceae	Betula nigra	River Birch	AC
	*Caesalpiniaceae	Cassia fasciculata	Partridge Pea	AB
		Gleditsia triacanthos	Honey Locust	AC
	Campanulaceae	Specularia perfoliata	Venus's Looking-Glass	A
	Caprifoliaceae	Symphoricarpus orbiculatus	Coral Berry	ABC
	Caryophylaceae	Cerastium vulgatum	Chickweed	A
		Dianthus armeria	Deptford Pink	A
		Silene antirrhina	Catchfly	A
	Chenopodiaceae	Chenopodium sp.	Pigweed	BC
		Kochia scoparia	Summer Cypress	BC
	Compositae	Achillea milefolium	Yarrow	A
		Ambrosia artemisiifolia	Ragweed	BC
		Ambrosia bidentata	Ragweed	ABC
		Ambrosia trifida	Horse weed	C
		Antennaria plantaginifolia	Pussy's Toes	A
		Artemisia annua	Sweet Wormwood	BC
		Aster pilosus	Aster	ABC
		Bidens polylepis	Tickseed Sunflower	ABC
		Cirsium altissimus	Tall Thistle	C
		Cirsium vulgare	Thistle	ABC
		Erigeron canadensis	Fleabane	ABC
		Erigeron strigosus	Daisy Fleabane	A
		Erigeron sp.	Fleabane	A
		Eupatorium altissimus	Tall Thoroughwort	C
		Eupatorium serotinum	Late Boneset	ABC
		Helianthus hirsutus	Sunflower	C
		Lactuca canadensis	Wild Lettuce	ABC
		Lactuca Scariola	Prickly Lettuce	ABC
		Lactuca sp.	Lettuce	ABC
		Rudebeckia hirta	Black-eyed Susan	A
		Solidago missouriensis	Goldenrod	A
		Solidago nemoralis	Old-field Goldenrod	ABC
		Solidago petiolaris	Broadleaf Goldenrod	A
		Tragopogon dubius	Goat's Beard	A
		Vernonia baldwini	Ironweed	AB

(continued)

TABLE 2. (continued)

CLASS	FAMILY	SPECIES	COMMON NAME	MINE
Angiospermae				
Subclass				
Dicotyledoneae	Cruciferae	Barbarea vulgaris	Yellow Rocket	A
		Brassica juncea	Mustard	A
		Lepidium densiflorum	Pepper Grass	AC
		Lepidium virginicum	Pepper Grass	ABC
	Ebenaceae	Diospyros virginiana	Persimmon	A
	Euphorbiaceae	Acalypha gracilis	3-seeded Mercury	B
		Acalypha virginica	3-seeded Mercury	A
		Croton capitatus	Hogwort	BC
		Euphorbia maculata	Nodding spurge	A
	Fagaceae	Quercus alba	White Oak	BC
		Quercus imbricaria	Shingle Oak	AB
		Quercus palustris	Pin Oak	A
		Quercus velutina	Black Oak	BC
	Hyperacaceae	Hypericum punctatus	St. John's-wort	B
	Labiatae	Labiate sp.	Mint	C
		Monarda fistulosa	Wild Bergamot	C
	Moraceae	Maclura pomifera	Osage Orange	A
	Onagraceae	Oenothera biennis	Evening Primrose	A
	Oleaceae	Fraxinus americana	White Ash	AC
		Fraxinus pennsylvanicans	Red Ash	C
	Oxalidaceae	Oxalis stricta	Yellow Wood Sorrel	A
	*Papillionaceae	Cercis canadensis	Redbud	C
		Coronilla varia	Crown Vetch	A
		Desmodium canescens	Beggar's Lice	A
		Lespedeeza stipulaceae	Lespedeza	ABC
		Medicago sativa	Alfalfa	ABC
		Melilotus alba	White Sweet Clover	ABC
		Melilotus officinalis	Yellow Sweet Clover	ABC
		Robinia pseudoacacia	Black Locust	ABC
		Trifolium prutense	Red Clover	ABC
		Wisteria frutescens	Wisteria	B
	Phytolacaceae	Phytolacca americana	Pokeweed	AC
	Plantaginaceae	Plantago aristata	Plantair	A
		Plantago virginica	Plantair	A
	Plantaceae	Plantanus occidentalis	Sycamore	A
	Polygonaceae	Polygonum aviculare	Knotweed	AC
		Polygonum lapathifolium	Smartweed	AC
		Polygonum pennsylvanicum	Pinkweed	ABC
		Rumex acetoseila	Sorrel	ABC
		Rumex altissimus	Pale Dock	C
		Rumex crispus	Sour Dock	BC

(continued)

TABLE 2. (continued)

CLASS	FAMILY	SPECIES	COMMON NAME	MINE
Angiospermae				
Subclass				
Dicotyledoneae	Rhamnaceae	Ceanothus americanus	New Jersey Tea	B
	Rubiaceae	Galium aparine	Bedstraw	A
		Fragaria vesca	Strawberry	A
	Roseaceae	Geum lancinatum	Rough Avens	A
		Potentilla simplex	Cinquefoil	A
		Prunus serotinum	Black Cherry	A
		Rosa setigeria	Prairie Rose	C
		Rubus flagellaris	Dewberry	ABC
		Rubus ostryfolius	Blackberry	ABC
		Rubus sp.	Bramble	ABC
	Salicaceae	Populus deltoides	Popular	AC
		Salix interior	Sandbar Willow	AC
		Salix nigra	Black Willow	C
		Salix rigida	Willow	C
	Solanaceae	Solanum carolinense	Horse Nettle	A
		Solanum rostratum	Buffalow Bur	C
	Typhaceae	Typha latifolia	Cattail	ABC
	Urbelliferae	Daucus carota	Wild Carrot	AC
	Ulmaceae	Ulmus americana	Elm	C
		Ulmus rubra	Slippery Elm	A
	Valerianaceae	Valerianella radiata	Corn Salad	A
	Verbenaceae	Verbena stricta	Vervain	A
	Violaceae	Viola Kitaibeliana	Johnny-jump-up	A
	Vitaceae	Parthenocissus quinquefolia	Virginia Creeper	A
		Vitis aestivalis	Summer Grape	ABC

*-Legumes

A-Abandoned Mines

B-Strip Mine 1

C-Strip Mine 2

Vegetation Identification

The floral composition of three Missouri strip mines is listed in Table 2. Principal invaders of surface mines studied in this project are representatives from five major plant families: Gramineae, Papilionaceae, Caesalpiniaceae, Compositae, and Polygonaceae. These colonizers are characterized by a high degree of acid tolerance and drought resistance. Large seed sets and long range dispersal (i.e., wind) are necessary for effective colonization.

It is of interest to look at the species composition in a pre-law mine site (Table 3). This mine was aerially seeded with a mixture of Kentucky 31 fescue and alfalfa, making up 46.7 and 39.2% of the biomass, respectively. Several other species such as cattail, sweet clover, smartweed, Indian Hemp, and barnyard grass collectively made up an additional 12.2%. The importance value which is the addition of percent frequency and percent biomass shows that alfalfa is of equal importance to the fescue.

Species numbers and importance values were determined for all of the pre-law and post-law sites with results showing that induced pasture species were outnumbered by weedy herbs but had greater importance values (Figures 5 and 6).

The slight increase in the number and decrease in dominance of pasture species in post-law sites is due to leveling to a rolling terrain. Less erosion greatly enhances the probability of a new species being established. Natural vegetation becomes established more quickly in post-law sites and distribution of vegetation types is more even than in pre-law ones.

An increase in the number of woody species in pre-law sites is due to the older condition of the mine (Figure 7). Advanced successional stages tend toward a woody condition if not managed.

Fourteen species comprimise 90% of the total importance value in all mines. The remaining species (51%) are relatively unimportant in terms of relative frequency and contributing biomass but may be very important in terms of stability (Figure 8).

TABLE 3. VEGETATIVE SPECIES COMPOSITION IN PRE-LAW SITE 2 AT STRIP MINE 3 SEEDED TO PASTURE

Species	Frequency		Biomass		Importance Value*
	Absolute	%	g/m^2	%	
Medicago sativa	.813	34.2	81.6	41.1	75.3
Festuca elatior	.653	27.4	81.3	41.0	68.3
Melilotus officinalis	.120	5.0	7.4	3.7	8.7
Ambrosia bidentata	.186	7.8	1.6	.8	8.6
Typha latifolia	.080	3.4	9.6	4.8	8.2
Polygonum pennsylvanicum	.133	5.6	4.2	2.1	7.7

(continued)

Species	Frequency Absolute	%	Biomass g/m²	%	Importance Value*
Lactuca canadensis	.146	6.1	.86	..4	6.5
Echinocloa muricata	.040	1.7	2.7	1.4	3.1
Apocynum cannabinum	.013	.5	4.2	2.1	2.7
Rumex crispus	.053	2.2	.69	.4	2.6
Agrostis hiemalis	.013	.5	1.9	1.0	1.5
Salix interior	.026	1.1	.78	.4	1.5
Trifolium hybridum	.013	.6	.51	.3	.9
Setaria glauca	.013	.6	.26	.1	.7
Gleditsia tricanthos	.013	.6	.26	.1	.7
Poa pratensis	.013	.6	.26	.1	.7
Eupatorium serotinum	.013	.6	.24	.1	.7
Unidentified shrub	.013	.6	.12	.1	.6
Asclepias incarnata	.013	.6	.05	.1	.6
Lepidium sp.	.013	.6	.005	.01	.6
Total	2.380	100.4	198.5	100.0	200.4

*Importance Value = % Frequency + % Biomass for a given species.

Species Diversity

Plant species richness, a measure of diversity, is proportional to the area sampled (Figure 9). Such species area relationships are typical of terrestrial ecosystems. However, the curves for replanted strip mines do not rise as quickly to an apparent plateau as they do for most natural communities. This is because the few pasture species greatly dominate the areas sampled.

Comparison of pre-law and post-law sites covered with spoil material shows the same species richness. However, the single topsoiled site studied in this project has a much greater number of species than the other sites. Most of these additional plants are weedy forbs.

Although the absolute number of species is equitable between pre-law and post-law sites, post-law sites have greater diversity per unit area (Figure 10). Management type rather than the age of the mine is the major factor contributing to high plant diversity. A topsoiled site shows greatest diversity per unit area.

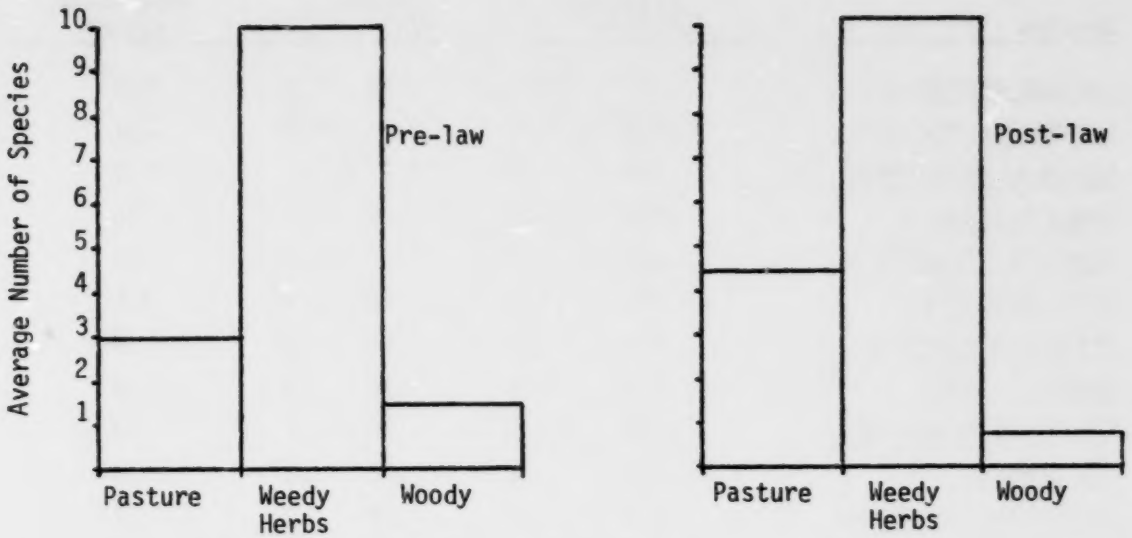


Figure 5. Number of species in vegetation types in pre-law and post-law mine sites.

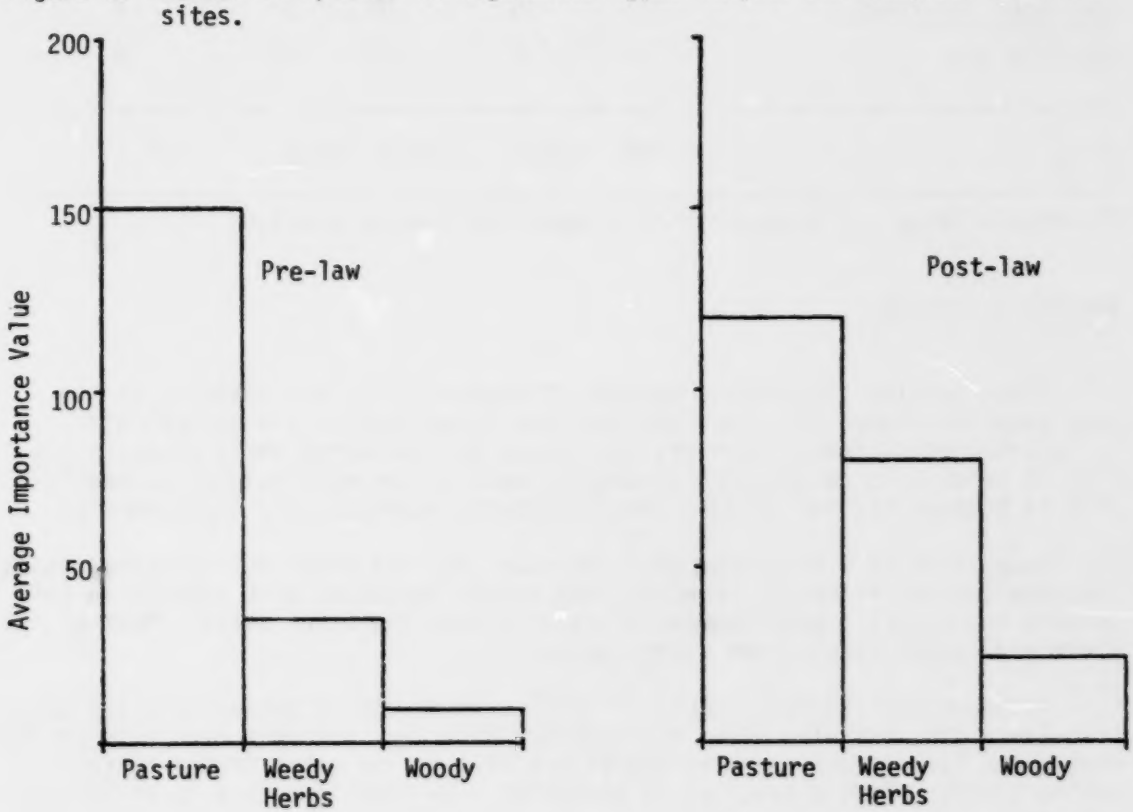


Figure 6. Importance of vegetation types in pre-law and post-law mine sites.

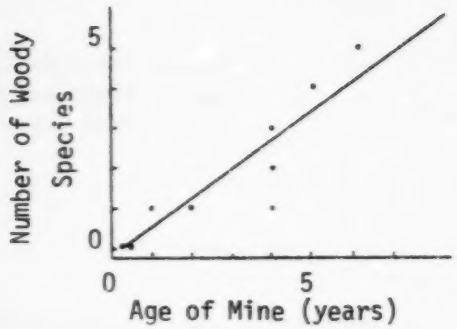


Figure 7. Increase in woody plants with age of surface coal mines.

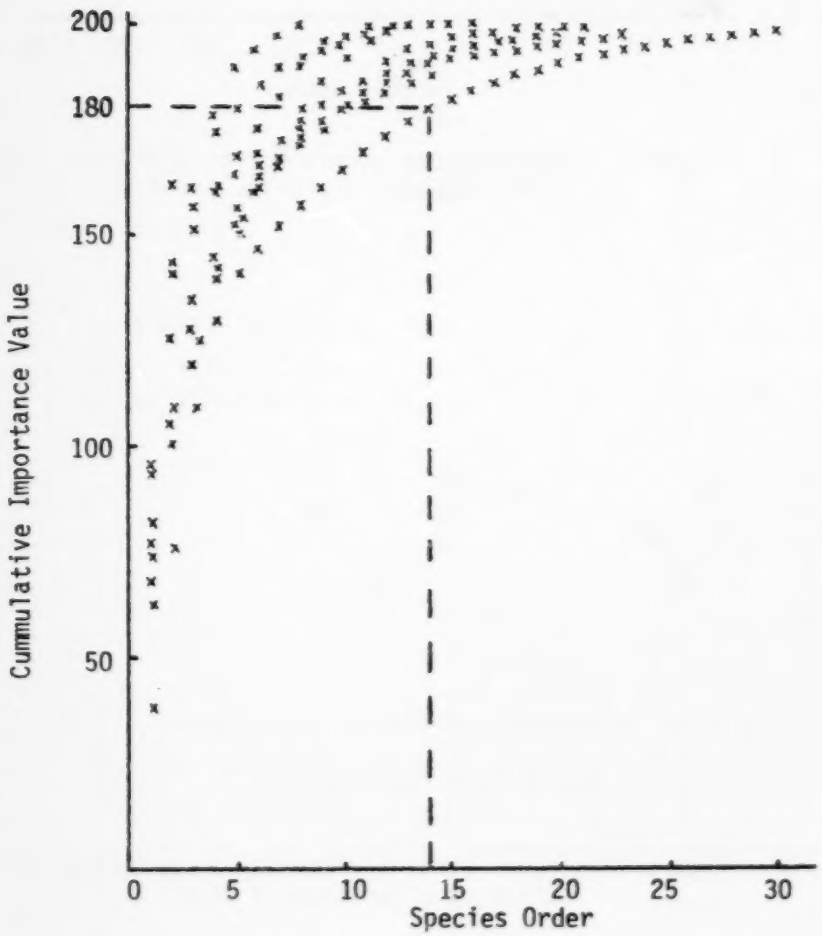


Figure 8. Importance value curves for nine mine sites.

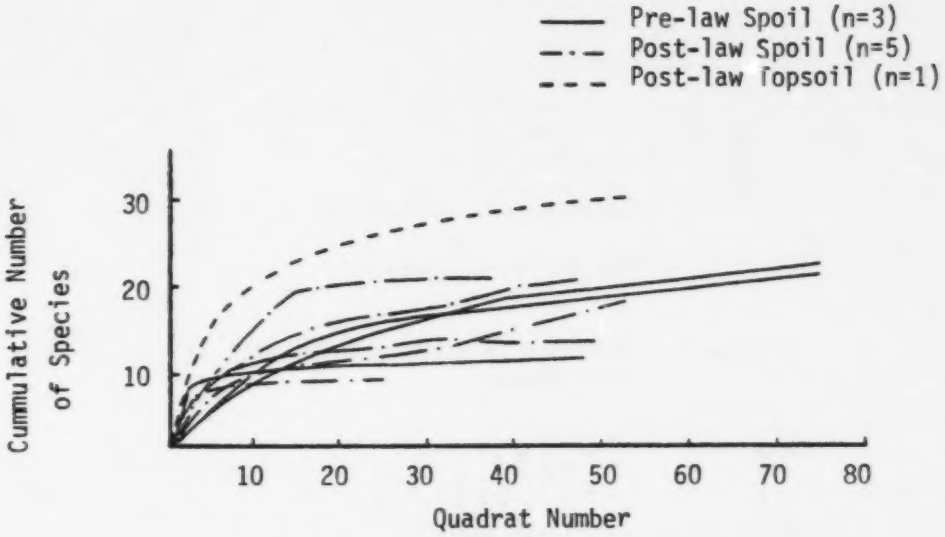


Figure 9. Species-area curves for nine Missouri strip mine sites reseeded to forage species.

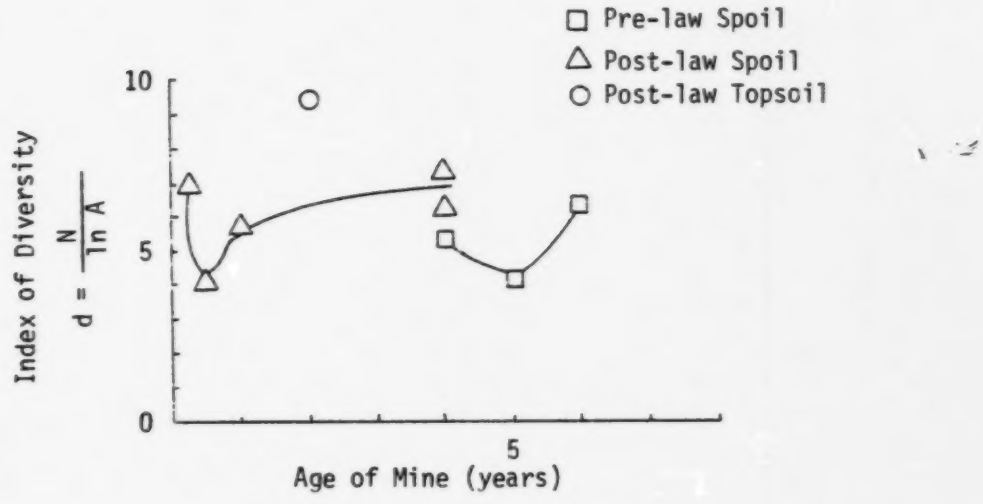


Figure 10. Plant species diversity in reseeded surface mines as a function of time.

Productivity

Productivity of minelands appears to increase with age more rapidly in gently rolling, post-law mines than in steeply sloping pre-law ones (Figure 11A and B). The difference between the sites is due largely to slope and aspect related stresses on plant growth and survival, and does not appear to be due to soil texture or chemistry (Carrel et al., 1978b).

The topsoiled, post-law mine after three years is as productive as spoil areas of comparable age (Table 4). There are no differences in growth of forages at the topsoiled site as compared to post-law sites of spoil material.

Wheat, a cultivator nurse crop, ceases to contribute biomass after 1 or 2 years (Tables 4 and 5). Its rapid growth and high initial productivity probably contributes some organic matter but more importantly provides soil stability and increased water intake.

Forage species show a continuous increase in productivity at most sites during the first 4-5 years of growth but legumes decline after 2-5 years (Figure 11B and Tables 4 and 5). Differences among sites reflect time of planting and sampling as well as edaphic variations.

A great deal of flux is observed in annual productivity among different sites (Figure 12). This appears to be a direct reflection of the successional state or age of mines. Change is great during the first 2 years as the nurse crop dies and forages grow. After 2-4 years in pre-law and post-law sites, a peak in productivity is reached. Thus, levels of stability first tend to increase with age, then decrease.

Sites exhibiting low productive stability do not exhibit a low index of diversity (Figure 13). This is contrary to ecological theory for plant communities undergoing natural succession. But since a number of forage and nurse crop species were planted in these mine sites, one would not expect a typical diversity - stability relationship to be seen. Perhaps after a decade, if these sites were not managed, there would be a positive correlation between species diversity and stability of production.

TABLE 4. 1977 VEGETATIVE PRODUCTION BY VEGETATIVE GROUP OF THREE MISSOURI STRIP MINES IN DIFFERENT STAGES OF RECLAMATION

Standing Crop (g/m^2)

Plant Name	Post-law Sites						Pre-law Sites		
	.25 yr.	.5 yr.	1 yr.	2 yr.*	4 yr.	4 yr.	4 yr.	5 yr.	6 yr.
Wheat	26.2	96.4	108.1	28.4	3.6	1.6	0	0	0
Fescue	0	15.0	9.9	44.7	149.4	130.9	81.3	84.3	114
Legumes	30.4	36.0	24.7	76.7	46.4	60.3	81.6	53.6	93
Weeds	64.7	96.9	73.2	42.2	69.5	24.6	36.1	10.1	80
Totals	121.3	244.3	215.9	192	268.9	217.4	199	148	287

*Topsoiled site, all others covered with spoil material.

TABLE 5. 1978 VEGETATIVE PRODUCTION BY VEGETATIVE GROUP OF THREE MISSOURI STRIP MINES IN DIFFERENT STAGES OF RECLAMATION

Standing Crop (g/m^2)

Plant Name	Post-law Sites						Pre-law Sites		
	1.25 yr.	1.5 yr.	2 yr.	3 yr.*	5 yr.	5 yr.	5 yr.	6 yr.	7 yr.
Wheat	0	0	0	0	0	0	0	0	0
Fescue	58	64.9	31.8	85.9	100.1	186.3	91.2	54.3	88.9
Legumes	25	31.8	81.5	37	23.7	14.1	60.2	38.7	37.6
Weeds	159.5	25.2	30.5	63	118.7	28	32.7	30.5	36.9
Totals	242.5	121.9	143.8	185.9	242.5	228.4	183.9	123.5	163.4

*Topsoiled site, all others covered with spoil material.

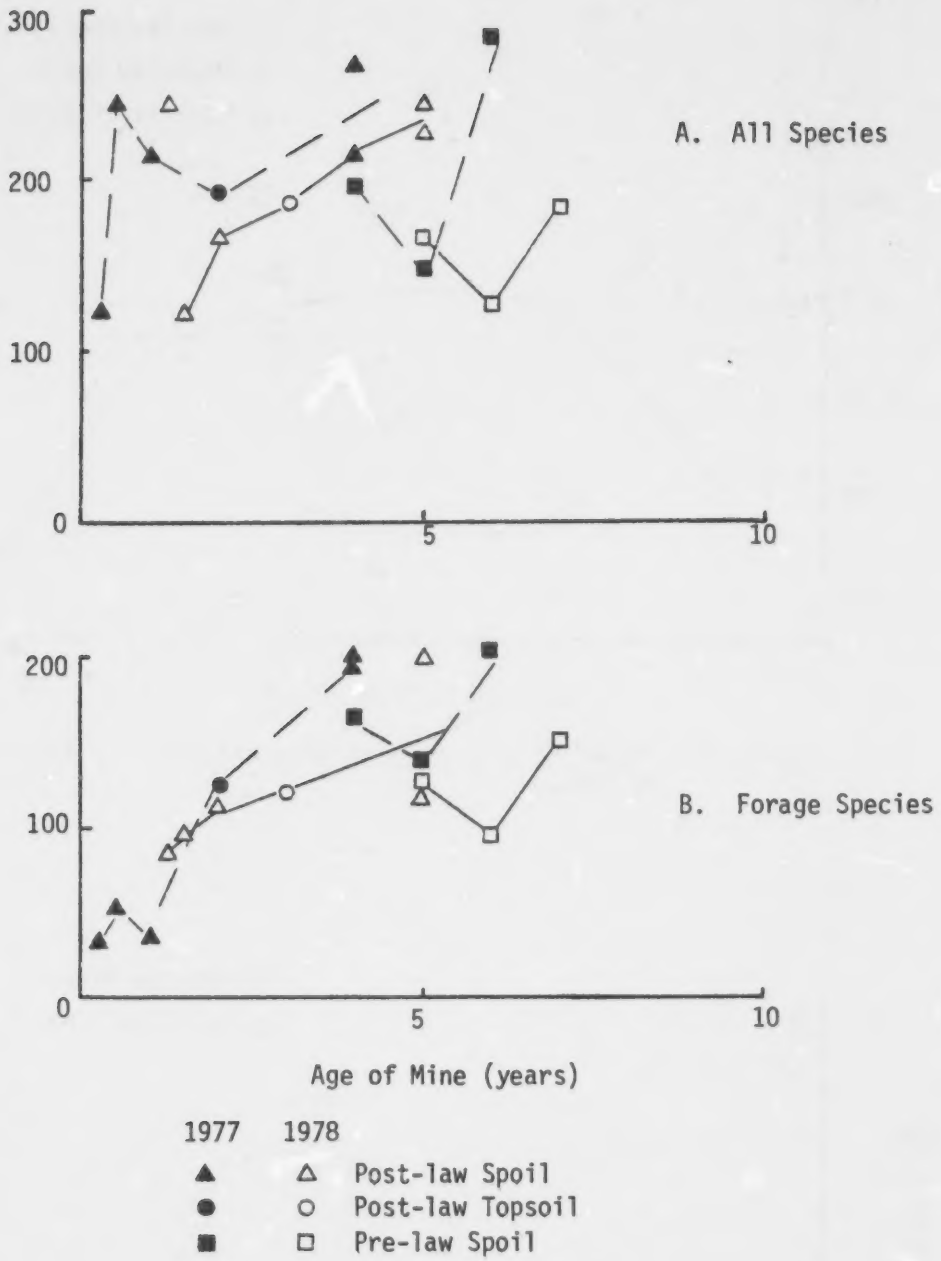


Figure 11. Productivity of vegetation in nine strip mine sites.

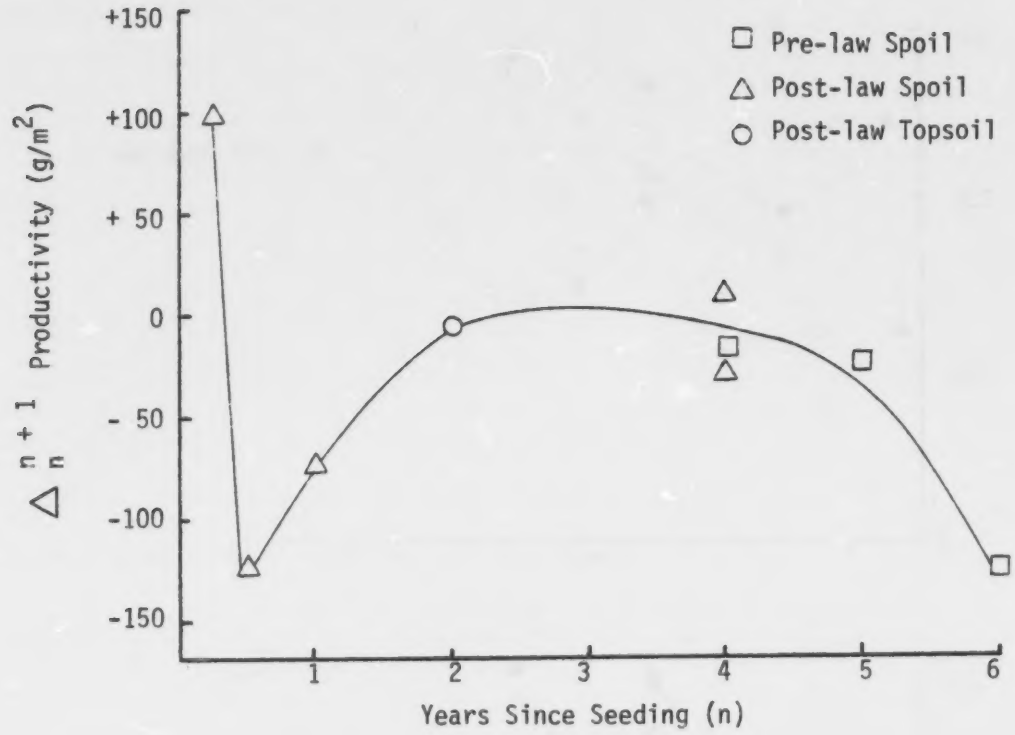


Figure 12. Annual change in plant productivity as a function of time.

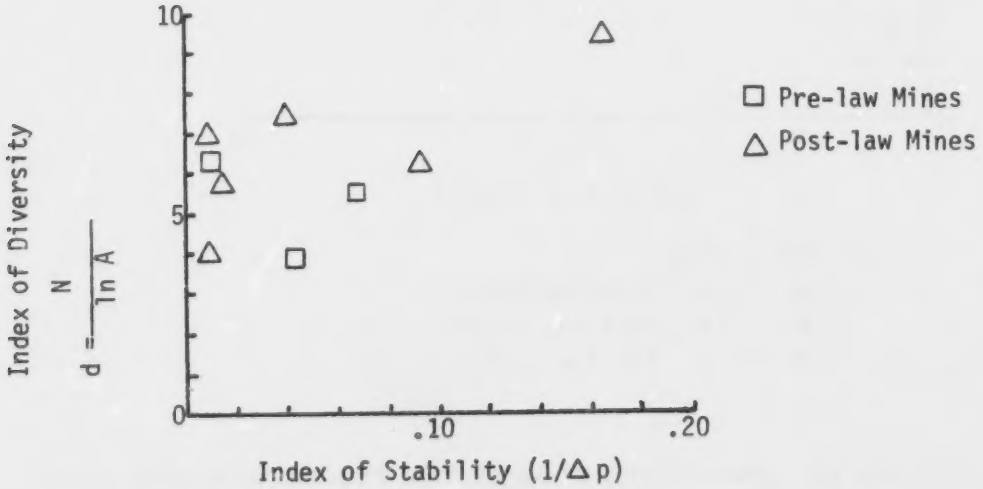


Figure 13. Relationship between diversity and stability in reseeded strip mines.

COMPUTER ANALYSIS

by

Dr. William McFarland and Terry Barney1/

METHODS AND PROCEDURES

This section reports on the development of a computer based technique for assessing the extent of revegetation on coal strip mine sites utilizing digital image scanning of color-infrared (CIR) aerial photography. The primary goal was the development of a technique that would offer a reasonable compromise, in terms of accuracy, time, expense and expertise, between manual photo interpretation and automatic machine processing strategies for assessment of vegetative ground cover on strip mine lands from remotely sensed data.

Digital Image Generation

The analysis techniques discussed in this report are based on the conversion of standard Kodak Aerochrome Infrared Film 2443 aerial photographs into digital images using an image scanner. The effective spatial resolution of the digital images analyzed is determined by three factors: (1) the spatial resolution of the scanner; (2) the size of the field of view scanned; (3) the scale of the aerial photograph. A field of view (FOV) is established for the image scanner that allows maximum presentation of a contiguous strip mine site. The field of view is measured at the image scanner, converted to the scale of the aerial photograph and then divided by the spatial resolution of the scanner and transferred to one of two displays for evaluation and analysis. The digital image is also stored on disk file for immediate recall and processing. The images can then be transferred from the disk file to nine-track magnetic tape for long-term storage.

The first task in the analysis of photographic images by computer is the construction of a digital image from the photograph. A digital image is a two dimensional array of numbers that represent the visual two dimensional image (photograph) to the computer. Because the computer can only operate on digital values (numbers), the digitized photograph represents the data input for all subsequent computer manipulations. All computer analysis of a photograph is based upon the digitizing process and the characteristics of the resultant digital image.

1/Associate Professor of Electrical Engineering and Bioengineering/Advanced Automation Program and Research Specialist, Extension Division, University of Missouri-Columbia.

A digital image has two primary components: spatial digital resolution and gray level resolution. The spatial digital resolution is the matrix size of the two dimensional array of numbers that constitutes the digital image. The digital image is thus composed of N points on a line with M lines constituting a complete image. The spatial digital resolution is expressed as N x M and represents a sampling over the field of view of the digitizing camera or scanner. The spatial digital resolution determines the effective spatial resolution of the digital image when the field of view (size of the area scanned) is considered. For example, taking a digital scan of 256 points (N) by 256 lines (M) over an area of photography 2 inches square (field of view) scaled at 1:2000 feet results in an effective sampling spot size of approximately 16 feet on a side. Therefore, each digital picture point (pixel) at that scale represents a true area of 256 square feet.

Gray level resolution in conjunction with dynamic range is the second primary component of a digital image. Dynamic range is defined as the range of film densities that the scanner can accommodate. Low contrast images present a small dynamic range while high contrast images present a large dynamic range. The number of different levels into which the scanner can divide its maximum dynamic range is defined as the gray level resolution. Most image scanners operate on a dynamic range of approximately 0-1.5 D with a resolution of 256 gray levels. These gray levels are called quantization levels and represent minimum contrast that can be detected.

A spatial Data Model 108 Computer Eye was used to digitize all aerial photographs at a spatial resolution of 256 x 240 with a gray resolution of 256 levels. A Ramtek GX 200 Color Display was used for display of the digital image at a spatial resolution of 256 x 240 with 16 levels of color within each of three primary colors giving a maximum color range of 4096 different shades of color. A Ramtek 9051 Black and White Display was also used to attain higher spatial resolution (up to 512 x 512) for display of the digital image and interaction with the user in selecting image parameters. The Graph-Pen Model GP-3 was used in conjunction with the displays for interactive data manipulation and processing. Nine track 800 bpi tape drives and disk drives were used for image storage and retrieval as well as program development and storage. The PDP-11 RSX-11M operating system and programs are primarily Fortran IV with some special purpose assembly language sub-routines.

Methodology Development

Three computer based techniques have been developed during this project for assessing the extent of revegetation on strip mined land utilizing digital image scanning of CIR aerial photography. Each technique attempts to separate the digital image of a strip mine site into three classes: water, vegetation and bare soil. The techniques differ in their method of determining gray level thresholds for class separation. The three techniques have been labeled: (1) training field method, (2) automatic gray level slicing from a histogram (clustering method) and (3) interactive gray level slicing (thresholding method). Results of repetitive scans were compared to evaluate the precision of each technique. Classification accuracies were evaluated by comparing the results to known ground cover quantified by quadrat and area metering methods of

established accuracy. The interactive gray level thresholding approach provided exceptionally consistent and accurate results within 3% of surface observations.

Technique Overview--

The training field method consists of displaying the digitized strip mine area on an interactive digital display and outlining areas in the image using an X-Y sonic pen and tablet. As the analyst moves the pen a line is generated on the display in direct relation to pen position. Any size or shape outline can be generated. Using this technique, the analyst: (1) identifies areas of water, vegetation and bare soil within the boundary of the strip mine sites; (2) delineates and identifies representative samples (training fields) for each class with the sonic pen; (3) evaluates the average gray level value and variance of each training field within each class; (4) calculates a representative mean value for each class and stores this information for classification of the entire mine site.

The automatic gray level slicing routine (clustering method) provides an image histogram, of the area to be classified, which displays frequency of occurence of gray level values (See Figure 14). The program automatically attempts to identify peaks and valleys in the histogram and slice it into three gray level clusters. If three distinct gray level clusters exist in the digital image, the histogram will reflect this with three distinct peaks and corresponding valleys. The minimum valley points are picked and used as separating points for the three classes. If the histogram does not reflect three clusters, the technique is unacceptable unless the analyst can use a two category classification.

The third technique, interactive gray level slicing, allows the analyst to interactively select thresholds to separate classes within the digital image. The digitized image is displayed on the interactive digital display and through the use of a joystick the user can "call-up" any threshold. For each threshold the display presents all points in the defined gray level slice as black with all other points white. Changing the displayed points takes less than two seconds, thus allowing for fast, accurate fine tuning of the desired threshold level.

Technique Evaluation--

Each technique was evaluated for precision and overall classification accuracy to determine which of the three would be best suited for routine and operational use. The interactive gray level slicing approach provided the best results. In developing the different techniques initial classification results indicated the training field approach might be superior to the interactive gray level slicing routine in terms of classification accuracy (See Table 6).

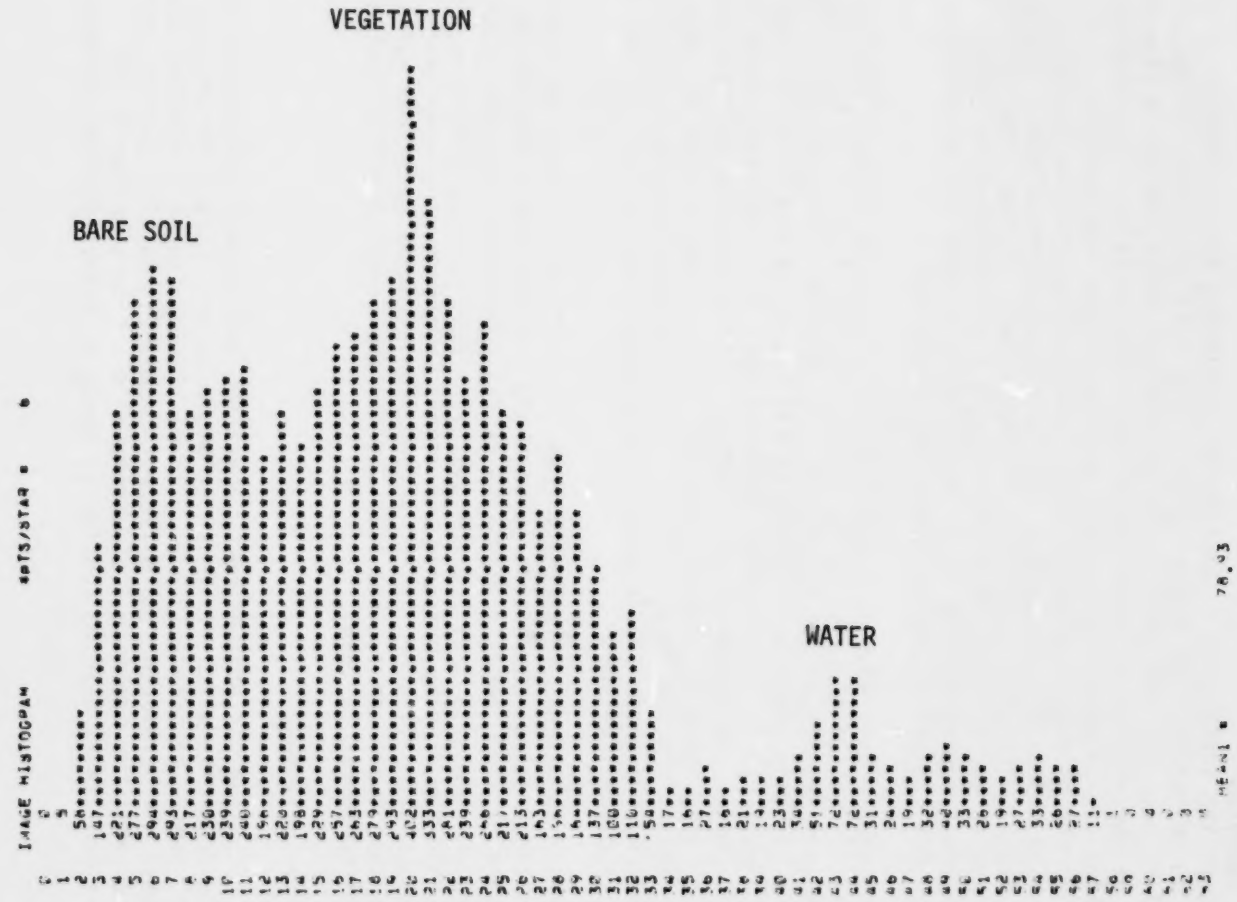


FIGURE 14. Digital image histogram showing general trends in gray level response distribution for bare soil, vegetation and water.

TABLE 6. PRELIMINARY COMPARISON OF OVERALL CLASSIFICATION ACCURACY BETWEEN INTERACTIVE GRAY LEVEL SLICING AND TRAINING FIELD TECHNIQUES

	Reference Standard Cover %	Computer Results Cover %
Interactive Gray Level Slicing Technique Pre-law Site 1, Strip Mine 1		
Vegetation	20.8	32
Bare soil	72.7	57
Water	6.5	11
Training Field Technique Post-law Site 1, Strip Mine 1		
Vegetation	48	56
Bare Soil	43	33
Water	9	11

Pre-law site 1 at Strip Mine 1 was selected as a control site for further evaluation of each technique. Reference standard acreage figures were compiled for each class. Each technique was used on three scans of the test site, each scan representing a new independent trial. It is virtually impossible to produce identical digital images from two scans of the same aerial photograph. The three separate scans were performed at one week intervals. The original site boundary used in the compilation of the reference acreages was stored on disk and reused for each technique and scan to hold that variable constant between computer and reference standard comparisons.

The results are shown in Figures 15, 16, and 17. Figure 15 indicates that while the cluster analysis does quite well on scan 2, there was considerable variance among the other scans. When the scanned image does not contain three peaks the classification accuracy of the clustering falls off dramatically and results are difficult to repeat. This routine is easily frustrated when contrasts between classes are not at a maximum, especially on pre-law sites or active sites where dark shaley material is still exposed on the surface and confused with vegetation. Figure 16 shows good consistency in the results for the training field method but a substantial error in classification between bare soil and vegetation occurred.

The precise results shown for the interactive gray level slicing (Figure 17) indicate that this approach is the most viable of the three in terms of precision and classification accuracy. Classification results fell within 3% of the reference measurements and repeated scanning produced nearly identical acreage figures. Classification accuracy was higher than expected. The scanning system alone is capable of introducing 3% noise error. This technique also proved to be a good compromise between the other two methods in considering the amount of time required to perform an analysis and problems associated with mine site type.

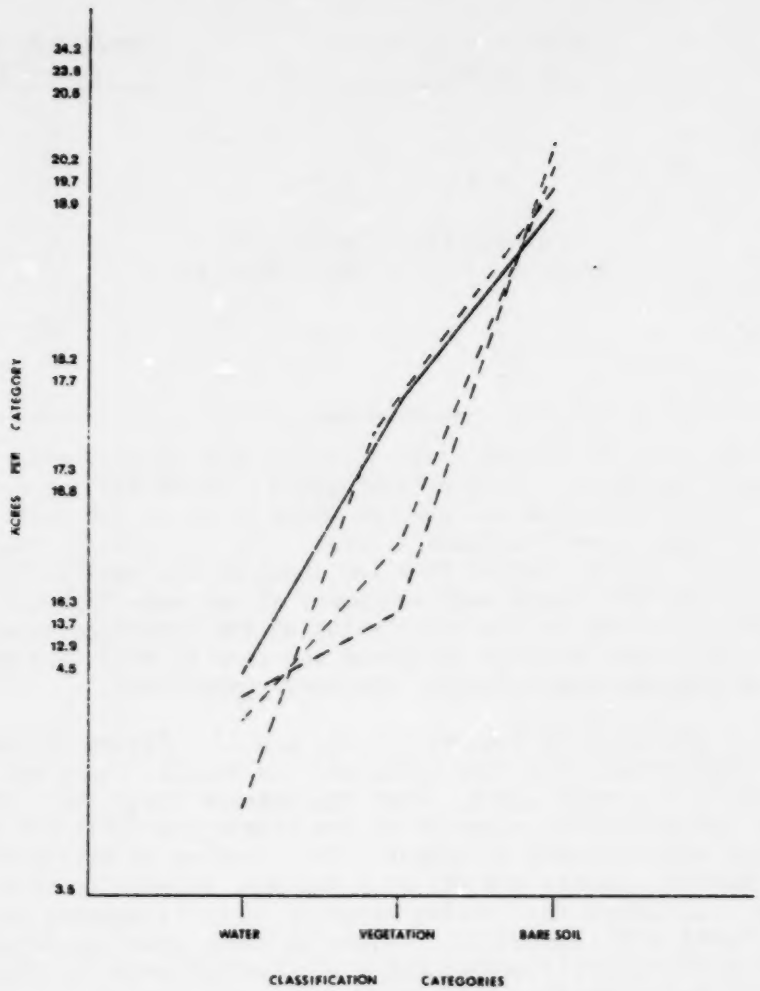


Figure 15. Technique evaluation results for automatic gray level slicing routine. Solid line is the reference standard. Broken lines are individual scans.

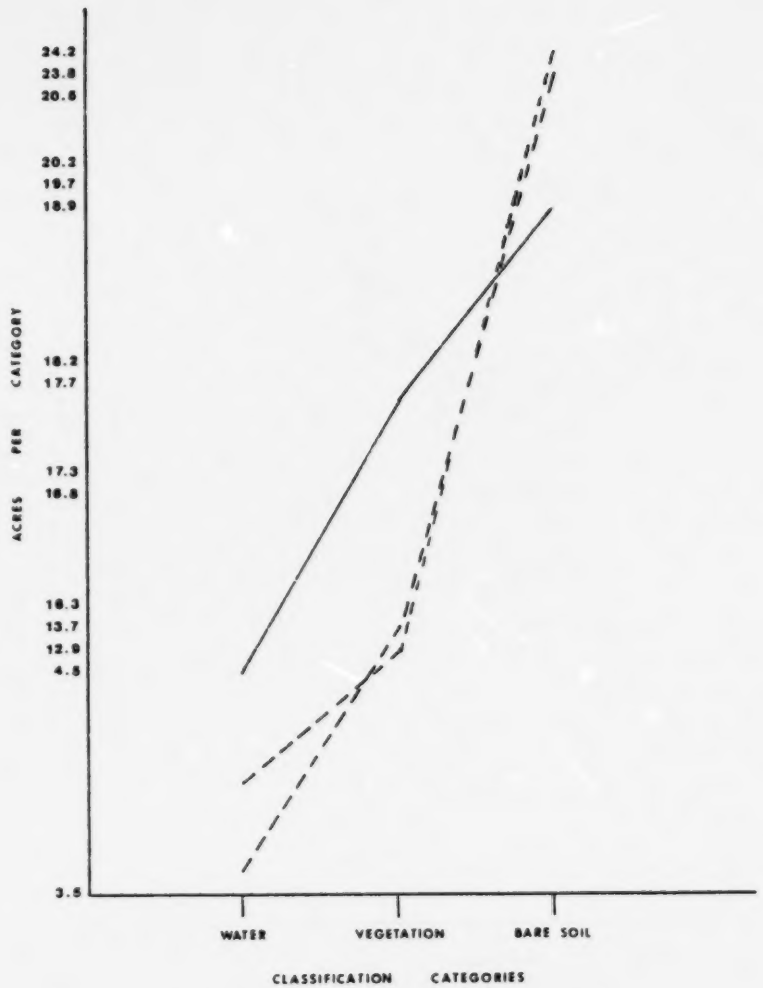


Figure 16. Technique evaluation results for supervised training field routine. Solid line is the reference standard. Broken lines are individual scans.

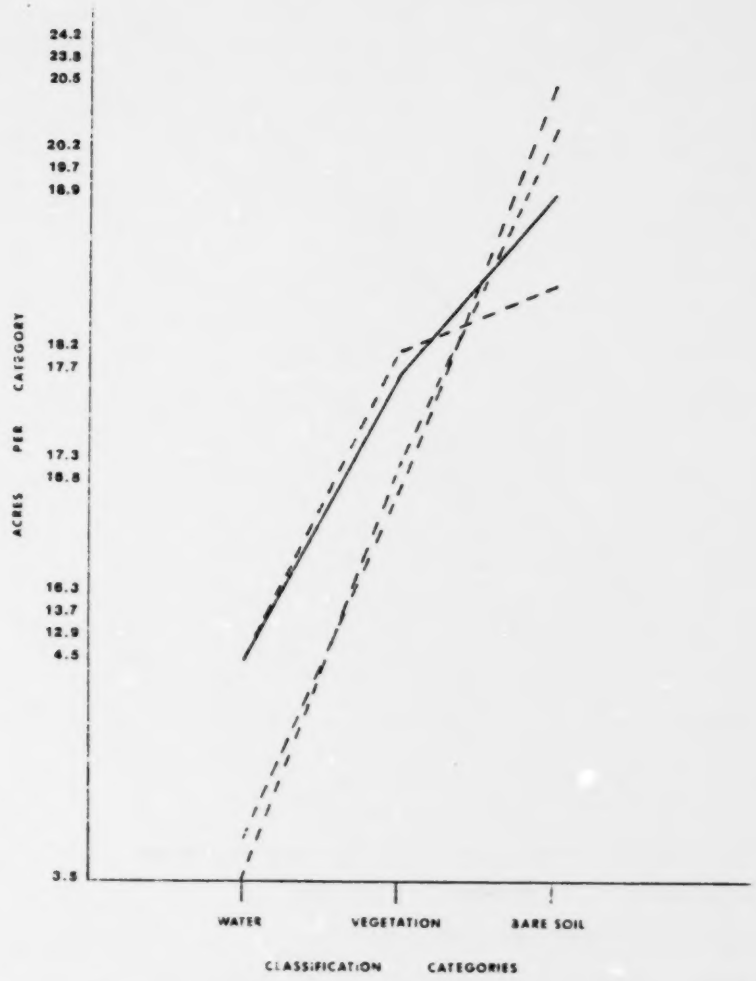


Figure 17. Technique evaluation results for interactive gray level slicing routine. Solid line is reference standard. Broken lines are individual scans.

The interactive gray level technique is easily adapted to both pre- and post-law mine site conditions and averages ten to twenty minutes for complete analysis of a mine site. The automatic gray level slicing routine only takes five to ten minutes but requires ideal contrast conditions to produce an accurate three category classification. The training field technique requires careful selection of training samples for the decision rule to accurately discriminate water, vegetation and bare soil. To approach the accuracies of the interactive technique would require an estimated two to three hours of analysis per mine site. Supervised training procedures are much more efficient when attempting classifications involving numerous classes where a high degree of accuracy is desired.

The Interactive Gray Level Slicing Technique--

This section expands the description of the interactive gray level slicing technique and sets forth the procedure followed in performing an analysis using the technique. Figure 18 summarizes the technique in flow chart form. The thresholding routine includes man-machine interaction to quickly assign a range of gray level values to areas of water, vegetation and bare soil. Working from the digitized image displayed on the interactive display (Figure 19), the analyst begins the process by selecting an initial threshold value to produce a gray level slice at the lower end of the gray level value scale. This corresponds to the class that appears the darkest on the displayed digital image. All picture points from Ø to the threshold cut off are set black and all others white. The analyst then visually evaluates the acceptability of a threshold for a particular class by comparing the displayed binary image with the original aerial photograph and the digitized image of the photo. Using the joystick the analyst can almost instantaneously change the threshold value until an acceptable proportion is obtained for a given class. Figures 20 and 21 show the digital display of gray level slices representing water and vegetation for post-law site 2 at Strip Mine 2. When the gray level slices are established for each class, the site boundary is delineated with the sonic pen and a point by point classification is performed on the entire site. A line printer printout (Figure 22) is made to present the results along with a tabulated summary of the number of picture points in each class. A scale factor is applied to translate these totals into acres.

Analysis procedure--An initial set up positioned the aerial photograph containing the mine site under the digitizing camera. Adjustments were made in camera height and focus to establish a field of view that allows the mine site to fill the digitizing area without any overflow. This eliminated the need for multiple scans to cover the entire site thus enhancing cost effectiveness. The actual size of the area to be scanned was measured for calculating pixel size and determining final acreage figures. With present optics, fields of view from 1 inch square to approximately 24 inches square can be accommodated. Regardless of the size of the field of view, the camera records a 256 x 240 matrix over the entire field of view.

Scanning and display--Once the field of view and scale factor were established, the aerial photograph was digitized at 256 x 240 points at a gray level resolution of 8 bits (256 levels). Prior to the actual digitization the scanning parameters were adjusted to insure a high quality digital image.

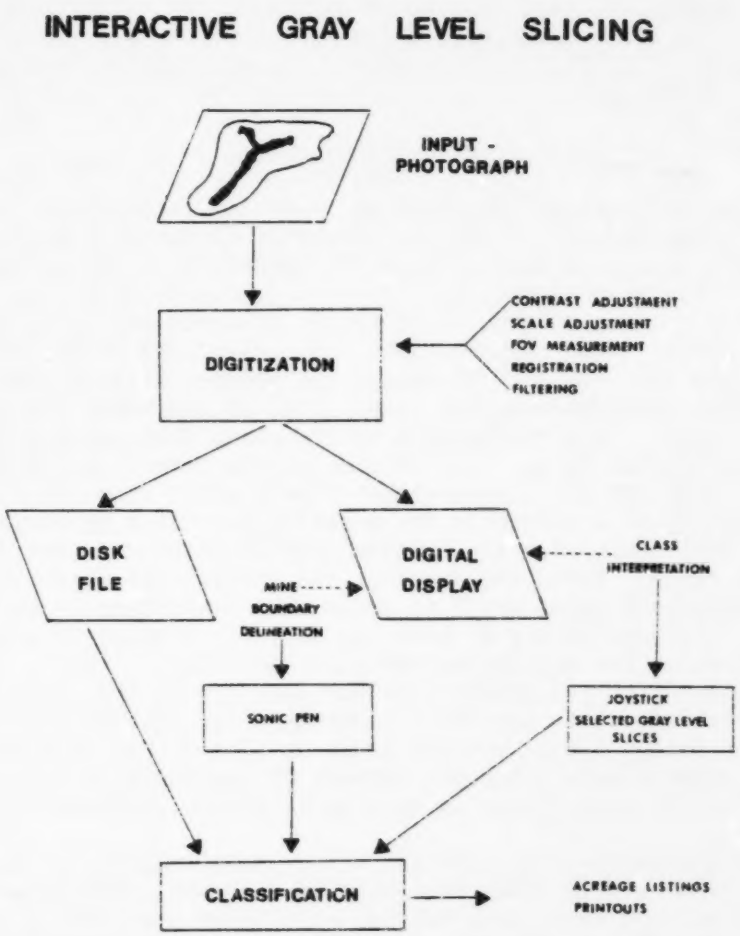


Figure 18. Interactive gray level slicing routine flow diagram.

Figure 19. A digital image of post-law site 2 at Strip Mine 2 as displayed on the black and white interactive digital display.

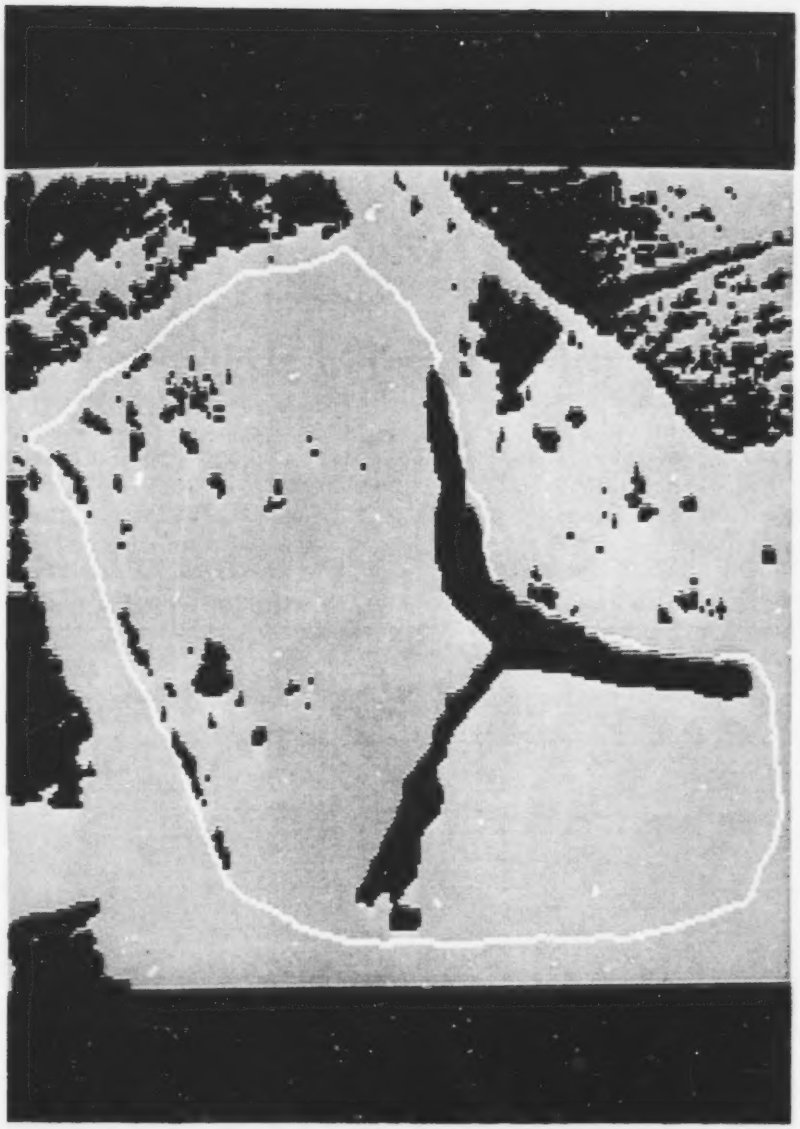


Figure 20. Digital display of gray level slice representing water (Black areas) within mine boundary (White) at post-law site 2, Strip Mine 2.

Figure 21. Digital display of gray level slice representing vegetation (Black areas) at post-law site 2, Strip Mine 2.

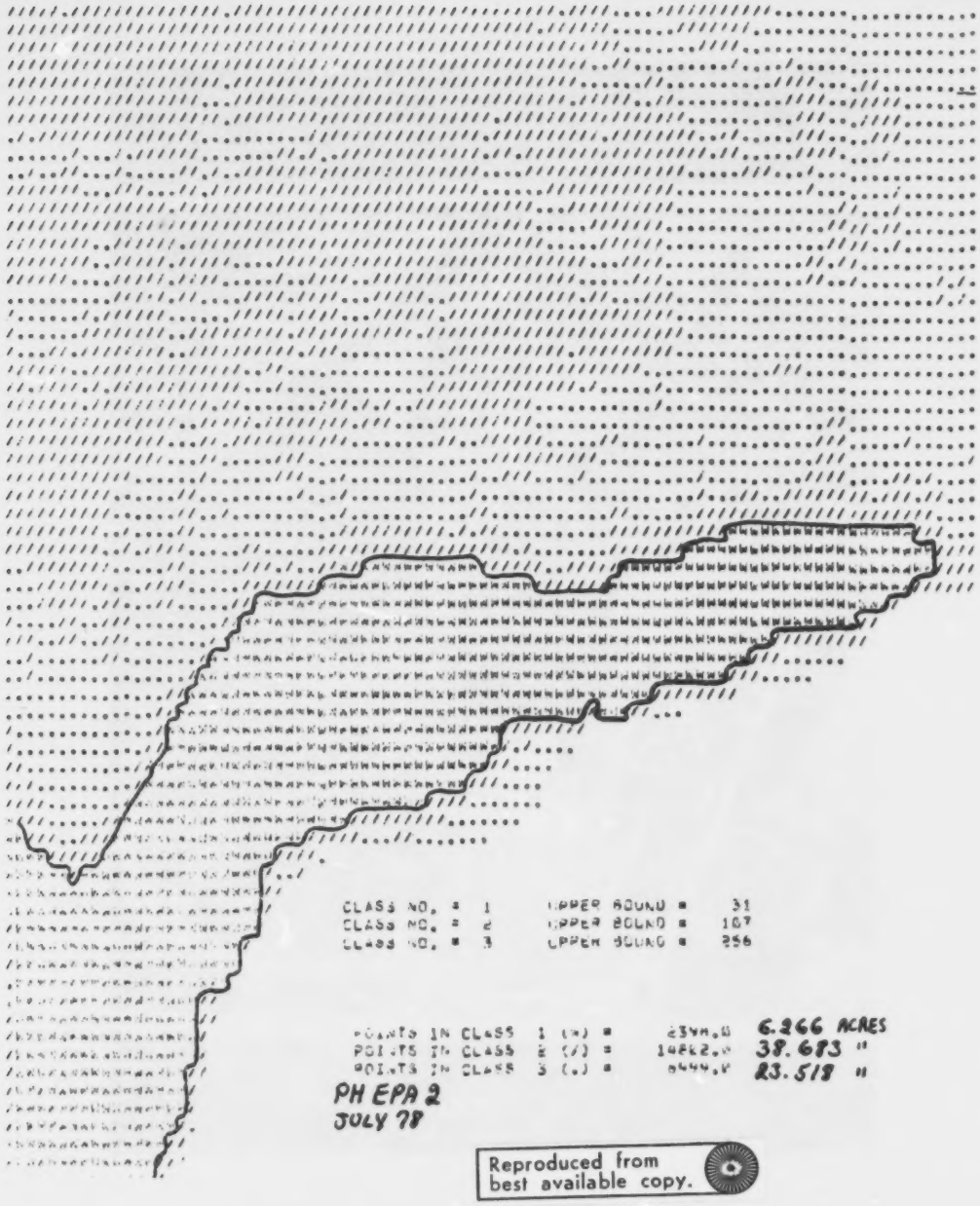

CLASS NO. = 1 UPPER BOUND = 31
CLASS NO. = 2 UPPER BOUND = 187
CLASS NO. = 3 UPPER BOUND = 256
POINTS IN CLASS 1 (W) = 23440 6.266 ACRES
POINTS IN CLASS 2 (/) = 148620 38.683 "
POINTS IN CLASS 3 (.) = 84490 23.518 "
PH EPA 2
JULY 78
Reproduced from best available copy.

Figure 22. Line printer output showing tabulated summary of picture points for each class, acreage conversion and the upper bound limits for the gray level slices. Classes shown are bare soil (·), water (W) and vegetation (/).

Adjustments included f-stop, digitizer range and zero adjustment. As the digital image was obtained from the scanner it was simultaneously stored on disk and transferred to the interactive black and white display memory. This task was accomplished in approximately one minute. The digital image was kept on display and the original aerial photo was moved to a viewing box adjacent to the display monitor.

Delineation of the mine site boundary--The mine site boundary was delineated on the digital image using the sonic pen and tablet. The analyst positioned a starting cursor on the mine site boundary by moving the pen to fix the cursor point at a starting location. The mine boundary was then outlined by the analyst locating the pen to move the cursor on the display to fall on the boundary of the mine site. The mine outline was stored on disk for later recall.

Interactive gray level slicing--A joystick was used to quickly vary the upper boundary of the gray level slice being displayed. The lower boundary was set, initially at zero, and the upper boundary was translated from the joystick position in its X direction. The analyst focused on the display and varied the joystick position to alter the size of the gray level slice. The display has a video table look-up option in its video generation that allows the entire 256 x 240 image to be sliced in 1/30th of a second. Ease of manipulation at this stage allows a desired gray level slice to be obtained and evaluated visually within minutes depending upon the geometric complexity of the class patterns. The threshold values selected for each gray level slice were recorded for subsequent classification.

Classification and print-out--The classification of the strip mine site is accomplished on a point by point basis for all points within the boundary delineated with the sonic pen. Each point was classified as water, vegetation or bare soil depending on its gray level value. The classification output was stored on disk and spooled out to the line printer which assigned selected characters to each point as a pseudo map output. Each character space represents a picture point on the image but the printout presents a scale and aspect ratio based on the mechanics of the printer. Figure 23 is a sample of the printer output. The printouts are useful for evaluation of spatial trends and overall technique performance in showing where there has been obvious misclassification. The printouts also summarize the number of picture points in each class from which acreage figures are calculated.

Accommodating Input Variables--

The input data for the computer based analytical process is photographic film. There are four major factors that influence the behavior of film when exposed and the character of the resultant image. These factors are: (1) film composition; (2) film handling; (3) film format; and (4) image acquisition. There are no absolute relationships between exposure of a film and the densities recorded. The ability of the analyst to group the resultant film densities (gray levels) into meaningful classes will be influenced to some degree by variables within each of the factors stated above. Only individual users can evaluate the tradeoffs between costs and classification accuracy in determining the extent to which individual variables will be accommodated. In this study the priorities were placed on absolute minimizing of costs while

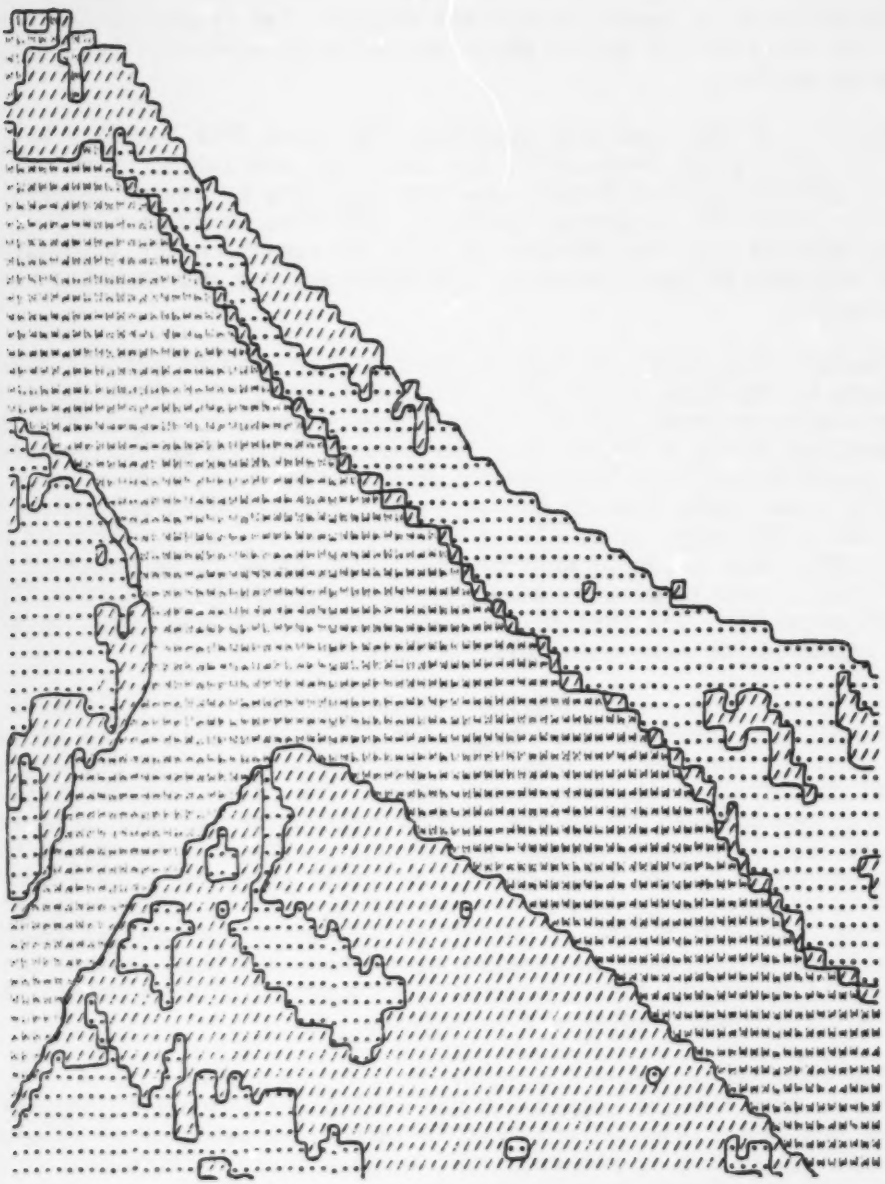


Figure 23. Line printer output upon which the individual classes have been delineated. Bare soil (·), water (W) and vegetation (/).

generating an acceptable degree of overall accuracy in classification results. Within this context, some variables were accommodated to varying degrees while others were left totally uncontrolled and accepted as recognized limitations on the technique.

In considering film composition, a major variable is the wavelength composition of the exposing light. This variable was accommodated through film type selection and minimal amounts of filtering during digitization. The emphasis on low cost ruled out the use of special multi-band film and camera packages and dictated the use of one standard readily available aerial film. Kodak Aerochrome Infrared Film Type 2443 was selected because it is a readily available standard product. Its sensitometric qualities provide excellent bare soil/vegetation enhancement as well as good discrimination between land and water interfaces. Also, the film is less susceptible to the influence of poor quality atmospheric conditions.

In addition to enhancing gray level separation through film type selection, better class separation can be obtained on some images using a combination of filtering and multiple scans. Specifically, a Kodak No. 25 red filter commonly used in color print processing, was used for better discrimination between water and vegetation. Computer programs were developed which allow two images to be classified and then combined to give a composite classification. The image is scanned without filtering. Vegetation and bare soil are classified allowing water to fall into either of the two other classes. A subsequent scan is made using the red filter. This image is classified into water and other. The two classifications are then combined to produce a composite three category classification of water, vegetation and bare soil.

Variables introduced through film handling procedures remained basically uncontrolled. Standard storage procedures were followed prior to and after exposure. Fluctuations in recorded film densities due to variations in processing were, to some extent, handled by adjustments of scanner parameters as the film was digitized. All 70mm film utilized in the study was developed using standard processing techniques for the 2443 film type. A majority of the classification work performed with the nine inch film utilized film negatives with altered color balance to further enhance contrasts on the mine sites. This can be accomplished at no extra cost over standard development to film positive format.

The principle variables in film format are image scale, actual image size and image base. Variations in film size and scale are accommodated by magnification. By utilizing a bellows system and various lenses, the field of view can be reduced to one square inch or enlarged to a 24 square inch size. This flexibility allows the analyst to use various scales of photography as well as film sizes. This study utilized both 70mm and 9 inch x 9 inch film sizes and contact scales of 1:6,000; 1:10,000; 1:24,000; and 1:46,000.

Registration becomes a serious requirement when comparisons want to be made of the same area with two different photographs (quite often of differing scales and format) on a point by point basis. While digital translation and rotation techniques can be used, they are very time consuming. Therefore, it

was elected to register images at the scanning input stage. This is accomplished by digitizing one image as a reference. This image is stored on disk and also displayed on the black and white display. Three points are located on this image and their x-y coordinates are read and displayed on a real time TV scanning monitor. The second image to be digitized is displayed simultaneously on the TV monitor. The scanning camera and photograph are repositioned such that the reference points overlay the three points displayed from the first image. Site boundaries delineated on the first image can then be accurately overlayed on the second image.

With regard to image base, film transparencies in positive and negative form and paper prints are available. Transparencies produce the best contrasts thus minimizing data degradation due to influences of image base material.

Variables introduced into the input data through image acquisition procedure were not accommodated. Calibrated RC-8 cameras were used for acquisition of 9 inch x 9 inch film. The 70mm camera was not calibrated. Scale fluctuations and distortions due to aircraft tilt and altitude variations went uncontrolled.

RESULTS AND DISCUSSION

Precision of Analysis

Precision can be evaluated independently of accuracy and should be used to denote the consistency of a measuring system. The ability to reproduce results on the same input data is the measure of precision. A digital computer will provide the same numbers whenever it is given exactly the same input data. The techniques developed have certain inherent process variables which make it impractical to expect exactly the same numbers upon repetition. The process variables include: (1) image contrast due to scanning parameters; (2) gray level slices due to analyst interpretation; (3) noise in the image scanner; and (4) field of view measurement. Table 7 shows the evaluation of precision based on analysis performed on pre-law site 1 at Strip Mine 1.

TABLE 7. PRECISION EVALUATION OF INTERACTIVE GRAY LEVEL THRESHOLDING, PRE-LAW SITE 1, STRIP MINE 1

	Bare Soil		Vegetation		Water	
	Acres	%	Acres	%	Acres	%
Reference Standard						
#1	18.9	46	17.6	43	4.5	11
#2	16.8	41	19.7	48	4.5	11
Computer Analysis						
Scan 1	20.3	49	16.3	40	4.4	11
Scan 2	20.2	49	16.5	40	4.3	11
Scan 3	19.7	48	17.4	43	3.9	9
*Scan 4	20.9	51	16.0	39	4.1	10
*Scan 5	20.5	50	16.0	39	4.5	11

Total Area = 41.0 Acres

*Analyst for #4 and #5 scans was the interpreter for reference standards #1 & #2

The first two rows of the table show the precision of the reference standard. This data was used as ground truth for comparison of computer results. It is interesting to note the variation between the two results. In each case the same photo interpreter using the same technique described in surface observation analyzed the same mine site at two different times. There was 5% variation in the classification of bare soil and vegetation. Water was consistent. Under computer analysis #4 and #5 are the results of this same photo interpreter using the computer and the interactive gray level slicing method. There is much better consistency between these two results (1%) than between the two reference standards. While the area classified water is practically the same in all four cases the areas called bare soil and vegetation vary 4%-9%, depending on which of the reference standards we choose to call correct. The other three runs are from three different scans at three different times employing the same photo interpreter-analyst responsible for the additional computer results in this report. Note that while these numbers are not exactly the same as in analysis scans 4 and 5 there is less variation between all five of these examples than between the two reference standards. This experiment shows the possibility that the interactive gray level slicing method is more precise, even between different analysts, than the reference standard interpretation.

Classification Accuracy

The primary goal of computer based approach to vegetative cover assessment was to combine the accuracy of conventional photo interpretation methodologies with the speed and efficiency of machine processing. Accuracy evaluation was based on comparing the total acreage figures compiled by the computer for each class to reference standard acreages compiled by the surface observations team with techniques of established accuracy. This approach evaluates the overall accuracy of each class. It does not reflect the accuracy of the classification on a pixel by pixel basis. At the time this study was performed, true-to-scale plotter output for the classifications was not available to check point by point accuracy.

Table 8 shows the overall accuracy figures for multiple scans of pre-law site 1 at Strip Mine 1 using the interactive gray level slicing technique. Computer error does not exceed 3% on any of the scans.

TABLE 8. ACCURACY OF INTERACTIVE GRAY LEVEL SLICING FOR MULTIPLE SCANS OF PRE-LAW SITE 1, STRIP MINE 1

	Computer Interpretations		Reference Standards		Computer Error	
	Area (acres)	Cover (%)	Area (acres)	Cover (%)	Area (acres)	Cover (%)
Scan 1						
Bare Soil	20.32	49	18.90	46	+1.42	+3
Vegetation	16.32	40	17.66	43	-1.32	-3
Water	4.44	11	4.52	11	- .08	0

(continued)

	Computer Interpretations Area (acres)	Cover (%)	Reference Standards Area (acres)	Cover (%)	Computer Error Area (acres)	Cover (%)
Scan 2						
Bare Soil	20.22	49	18.90	46	+1.32	+3
Vegetation	16.58	40	17.66	43	-1.08	-3
Water	4.28	11	4.52	11	- .24	0
Scan 3						
Bare Soil	19.71	48	18.90	46	+ .81	+2
Vegetation	17.48	43	17.66	42	- .18	0
Water	3.88	9	4.52	11	- .64	-2

Total area = 41.08 acres

It is important to note that the identical aerial photographs and mine site boundaries were used in all of the direct comparisons made between the computer results and the reference standard results. Table 9 lists the results for the additional evaluations of the interactive gray level slicing technique on both pre- and post-law sites at Strip Mines 1 and 2.

TABLE 9. CLASSIFICATION ACCURACY EVALUATIONS FOR ADDITIONAL PRE-AND POST-LAW SITES UTILIZING THE INTERACTIVE GRAY LEVEL SLICING TECHNIOUE

Mine Site 1/	Procedure 2/	Bare Soil Area (acres)	Cover (%)	Vegetation Area (acres)	Cover (%)	Water Area (acres)	Cover (%)	Total Area (acres)
2-1	Reference	27.0	38	27.5	39	16.7	23	71.2
	Computer	29.0	41	25.4	36	16.8	23	71.2
2-2	Reference	49.3	60	17.4	21	16.0	19	82.7
	Computer	42.4	51	19.1	23	21.2	26	82.7
2+2	Reference	49.5	80	6.7	11	5.2	9	61.4
	Computer	51.5	83	5.2	9	4.7	8	61.4
2+3	Reference	36.2	59	17.2	28	8.3	13	61.7
	Computer	31.6	51	23.0	37	7.1	12	61.7
1+2	Reference	9.6	23	22.8	56	8.8	21	41.1
(May)	Computer	11.1	27	23.2	56	6.8	17	41.1
1+2	Reference	4.7	11	28.0	69	8.4	20	41.1
(July)	Computer	4.9	12	28.6	70	7.6	18	41.1

1/ Strip Mine 1 or 2, site 1 or 2, pre-law (-), post-law (+).
2/ Reference acreages compiled by conventional photo interpretation and computer analysis by interactive gray level slicing.

The evaluation results indicate that the interactive gray level slicing technique is very competitive with the area metering manual photo interpretive method despite the fact that the computer is working from a disadvantage in

terms of effective spatial resolution. In general, the computer based approach cannot accurately measure objects less than two times the effective resolution and the preferred ratio is 5:1. The reference standard maps were compiled at a resolution (minimum mapping size) of .5m^2. In contrast, the effective spatial resolutions of the digitized images were always five to ten times the area metering resolution. Yet the computer technique produced comparable results.

Seasonal Variations

The aerial photography used in this study was collected May, July and October. As Tables 10, 11, and 12 indicated, there were sizable shifts in the overall acreages for the vegetation and bare soil categories at the mine sites where multi-temporal analysis was done. Factors influencing the amount and densities of vegetative cover which in turn affect total acreages when classification is carried out include: (1) strip mine type (pre- or post-law) and final landscape geometry; (2) special vegetation composition; (3) the age of the mine; (4) fertility treatments; and (5) time of year.

A primary component in assessing the cost effectiveness of a procedure is the ratio of the length of time required to perform the analysis to the size of the area analyzed. The interactive gray level slicing technique can accomplish a single scan evaluation in 10 to 20 minutes. Of course, the actual acreage classified for any given scan will depend on the size of the field of view and contact scale of the aerial photograph being digitized. Each of the seasonal evaluations shown in Table 12 took approximately 20 minutes. In contrast, the reference standard technique took 4½ hours. A traditional ground survey might have taken up to 20 hours had it been performed. Also note in Table 12 the wide range of scales that were accommodated with single scans.

TABLE 10. SEASONAL ACREAGE COMPARISONS FOR POST-LAW SITE 3, STRIP MINE 2.

	May, 1978 (acres)	October, 1978 (acres)
Bare Soil	23	7.6
Vegetation	31.6	45.0
Water	7.1	9.1
Total Acres	61.7	

TABLE 11. SEASONAL ACREAGE COMPARISON FOR POST-LAW SITE 2, STRIP MINE 1

	May, 1978 (acres)	July, 1978 (acres)
Bare Soil	11.1	4.9
Vegetation	23.2	28.6
Water	6.8	7.6
Total Acres	41.1	

TABLE 12. SEASONAL ACREAGE COMPARISON FOR POST-LAW SITE 2, STRIP MINE 2

Date:	May, 1977		October, 1977		July, 1978	
Air Photo Scale:	1:6,000		1:24,000		1:46,000	
	Area (acres)	Cover (%)	Area (acres)	Cover (%)	Area (acres)	Cover (%)
Bare Soil	51.9	84	26.2	42	21.2	34
Vegetation	5.2	8	31.2	51	34.9	57
Water	4.7	8	4.4	7	5.7	9
Total Area	61.8					

EROSION AND DRAINAGE ANALYSIS

by

Dr. D.J. Barr, C. Dale Elifrits and Shara McBee 1/

METHODS AND PROCEDURES

The prime objective of this phase of the project was to determine the effect of surface mining and reclamation practice on drainage pattern and slope shape and to estmate how their change might contribute to the erosion potential of a site. Investigators working in the Remote Sensing Laboratory at the University of Missouri-Rolla, interpreted and analyzed pre-mine and post-mine aerial photography to yield base maps of drainage pattern orientation. Although many photographs were interpreted, only those of suitable scale, quality and season of exposure were used in the preparation of the maps.

Summary of Appropriate Theory and Literature

During the initial stages of this study, a report entitled "Some Factors Affecting Erosion" (Brickner, 1977) was prepared so as to establish the accepted theories of erosion and drainage pattern development. In terms of how different slope profiles as illustrated in Figure 24 are affected by precipitation runoff and erosion, the following trends are generally accepted:

1. Concave slopes are least affected by erosion, yield the least amount sediment, and change shape slower than other profiles.

2. Convex slopes erode the fastest, yield the most sediment, and change shape faster than other profiles.

3. Uniform and complex slopes are affected to an intermediate degree although long uniform slopes can be severely eroded in a single rain storm.

4. All slope profiles will tend to erode to a concave shape, given sufficient time, and the steepness of the toe of the slope is most significant in overall erosion.

1/Professor, Graduate Instructor and Graduate Assistant, respectively, Department of Mining, Petroleum and Geological Engineering, University of Missouri-Rolla.

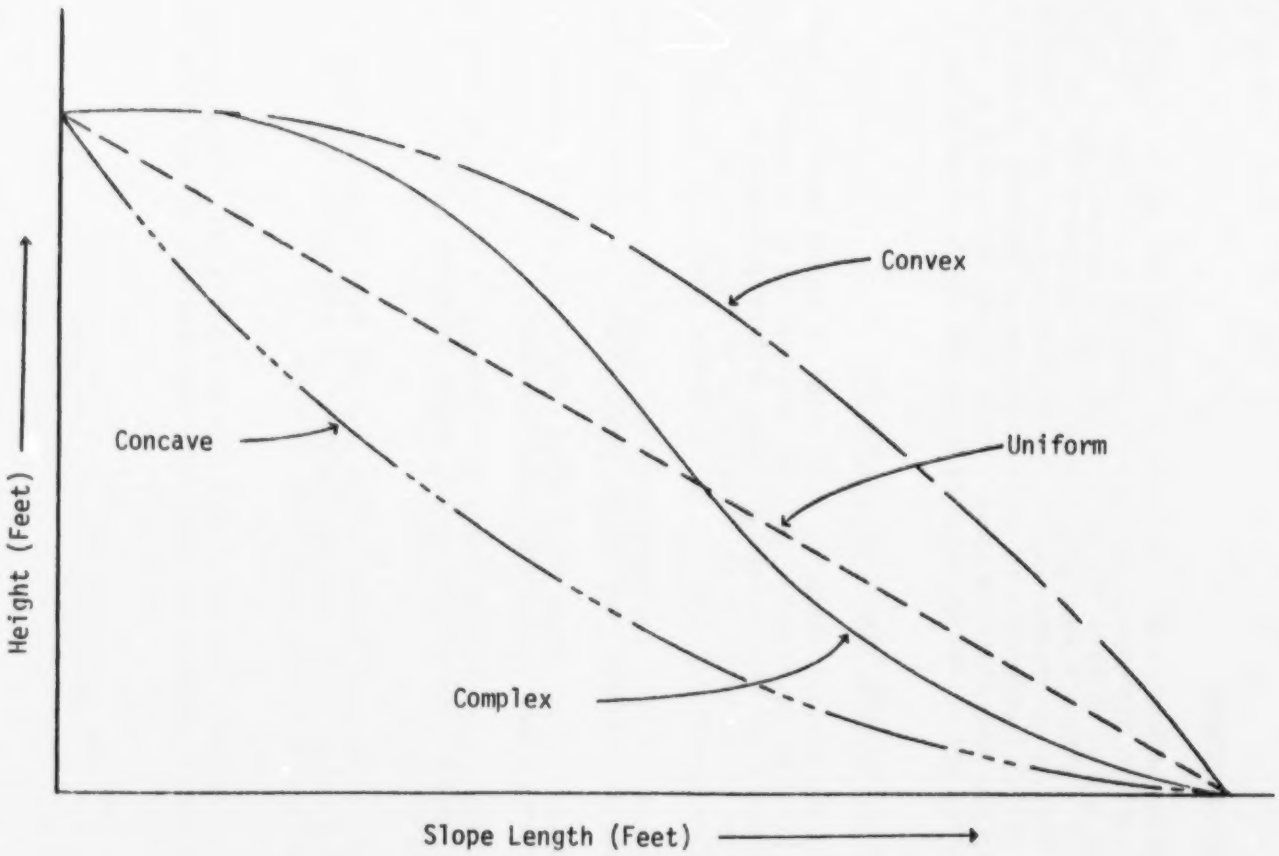


Figure 24. Slope profile shape for four different types of slopes.
Source: Brickner, 1977

Drainage patterns are created as a result of erosion. In a natural terrain without geologic or man-made controls, a totally random pattern defined as dendritic will result. The frequency of channel occurrence or density of pattern will be a function of rainfall, slope, geology, surficial soil type and vegetative cover. In general, the less permeable the soil, the greater will be drainage density. Any natural or man-made control that would tend to disrupt the hydrologic regime could increase the erosion potential.

Drainage Map Preparation

Panchromatic and color infrared aerial photography was used to delineate drainage patterns at the three strip mine sites. Color infrared photography was obtained at a scale of 1:6,000 in a photographic mission flown for this project and was also used in the Surface Observations and Computer Analysis studies. This photography provided post-mine drainage information. Sources for pre-mine panchromatic photography included the Missouri Historical Society, the Boone County Planning Department and the USDA Agricultural Stabilization and Conservation Service. This photography was of various scales and was obtained in missions flown in different years.

A base map was prepared for pre-mine and post-mine drainage at each site by tracing roads and cultural features on a base sheet. Whenever possible, only that portion of the photograph with the least amount of distortion, approximately the center two-thirds, was used. Clear and lightly frosted acetate were used as a base sheet. Lightly frosted acetate was originally used, but even with additional lighting, it was difficult to see the detail on the underlying photograph. Clear acetate proved to be much better as it allowed the interpreter to see details more clearly.

After the base maps were prepared, they were taped to a table and one photograph of a stereo pair was aligned under the base map. The second photograph was placed on top of the base map in such a way that the photographs could be viewed stereoscopically. While viewing the photographs stereoscopically, the interpreters traced the drainage paths with either colored pencils or ink onto the base map. The process was repeated until the drainage maps at each mine site were completed.

Both mirror and pocket stereoscopes were used to view the photography. Mirror stereoscopes were found to be superior in that they reduced eye fatigue and provided a wider field of view. As both mental and physical fatigue were encountered by interpreters while tracing drainage patterns, interpreters found that they were more efficient and precise if they spent approximately one hour tracing drainage and one-quarter of an hour involved with another aspect of the project before mapping drainage again.

After the drainage maps were interpreted and delineated, a Map-O-Graph Enlarger-Reducer was used to adjust the maps to a common scale of 1:24,000. The drainage maps were placed in the Map-O-Graph which projected an image of the map onto the topographic base map of that area. The image scale was then adjusted until the roads on the image matched those on the topographic map. The topographic map was then replaced by a piece of acetate so that the image of the drainage pattern could be traced.

Figures 25 and 26 represent pre-mine and post-mine drainage patterns for Strip Mine #1, Boone Co., Missouri. Pre- and Post-Mine drainage patterns for Strip Mine #2, Randolph County, Missouri are presented in Figures 27 and 28. Strip Mine site #3 contained pre-1950 mine areas. Thus, the pre-mine drainage indicated in Figure 29 contains older workings. Post-mine drainage patterns are presented in Figure 30.

Evaluation of Slope Geometry

In conjunction with drainage delineation, photo interpreters estimated the shape of pre-mine and post-mine ridges and hills from the three-dimensional view created by the stereoscopic photography. Slope profile shapes were defined as indicated in Figure 24.

Interpretations of pre-mine topography indicated that stream channel profiles and hillside slopes both exhibited a concave shape. This was in agreement with what one should expect for natural, undisturbed terrain.

The shape of hills and ridges was much more variable in those same areas after mining and after reclamation. Pre-law sites exhibited higher relief with convex to uniform slope profiles. Post-law sites exhibited less relief but longer uninterrupted convex to uniform slope profiles. In all cases, post mine conditions deviated significantly from the natural slope profile shapes as they existed prior to mining.

ANALYSIS PROCEDURES

Drainage Density

One way in which to estimate the degree of integration and completeness of drainage development is to calculate the drainage density of a given area. Drainage density is defined as the ratio of the total length of stream channel within a basin to the area of that basin ($D_d = \frac{\Sigma L}{A}$). In order to compare post-mine drainage density with pre-mine drainage density, representative areas larger than 0.2 sq. miles were selected from various portions of the pre-and post-mine drainage pattern maps of each of the three mine sites. A mechanical map measure was used to measure the total length of stream whereas a polar planimeter was used to measure area. Drainage densities as calculated by formula are summarized in Table 13.

TABLE 13. A SUMMARY OF PRE-MINED AND POST-MINED DRAINAGE DENSITY CALCULATED FROM DRAINAGE PATTERNS AS SHOWN IN FIGURES 25-30

Figure Number	Strip Mine Site	Pre-Mined Natural Drainage Density	Post-Mined (Mined Area) Drainage Density
25	1	11.13 miles/mi^2	
26	1		28.0 miles/mile^2 (pre-law) 13.9 miles/mile^2 (post-law) 17.9 miles/mile^2 (Composite)
27	2	12.5 miles/mi^2	

Figure Number	Strip Mine Site	Pre-Mined Natural Drainage Density	Post Mined (Mined Area) Drainage Density
28	2		10.44 miles/mile^2(post-law)
29	3	9.45 miles/mi^2 (including older mine sites)	
30	3		11.37 miles/mile^2

Strip Mine 1 drainage density values must be associated with their respective terrain conditions. The 28.0 miles of stream per square mile is a value measured from a section of land abandoned after mining was completed prior to the reclamation laws' effective date. This area is highly eroded and shows much gulley development in the spoil piles which were not regraded nor covered with soil. The rock materials of the spoil piles were not revegetated at the time of the photography from which this data was taken.

The area where 13.9 miles of stream per square mile were measured is an area where reclamation practices were applied some three to four years before the photography was taken. During the time since reclamation was completed, a drainage system has developed. The relative stream density developed on the terrain created by the application of reclamation practices can be seen as slightly higher than that of a natural terrain.

Strip Mine 2 drainage data values were measured from an area of recent (1-2 years old at the time of photography) reclaimed terrain. It can be seen that this relatively young terrain shows a lower than natural drainage density.

Strip Mine 3 drainage data is affected by the fact that part of the "pre-mined" mapped area is an area of previously disturbed land. This land was disturbed by mining prior to the date of the historical photography used to construct the drainage map. Thus the relative variation of stream density from "pre-mined" to "post-mined" time at this location is of low magnitude.

Drainageway Orientation

Two types of reorientation of the drainage system can be observed. One type is that of the elimination of random location of drainageways by the placement of designed terraces, diversions and waterways as the spoil piles are reshaped, thus leaving large segments of terrain not integrated into a drainage system. Examples of such areas can be seen on Figure 28 where large areas exist with no surface drainage pattern. Also, many of these designed drainageways are linear and in a parallel to rectangular pattern.

A second type of reorientation is the displacement of main channelways through the mine area. Frequently, this changes the length of channel (most often shortening it) and modifies the floodway of the channel. In the case of Strip Mine 2, the main channel of the Chariton River was moved to enhance coal recovery and production within the mine boundaries.

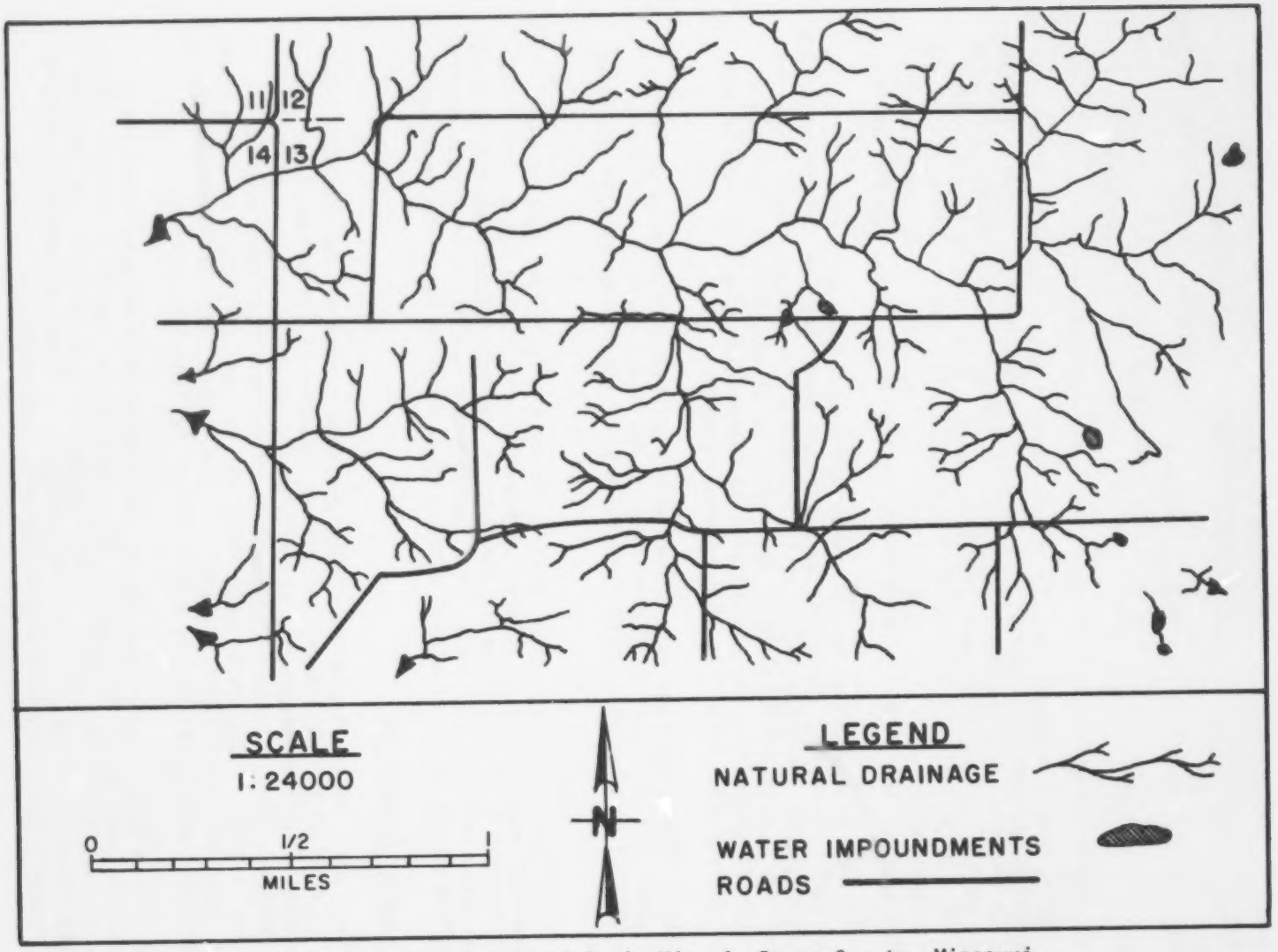


Figure 25. Pre-mining drainage patterns of Strip Mine 1, Boone County, Missouri.

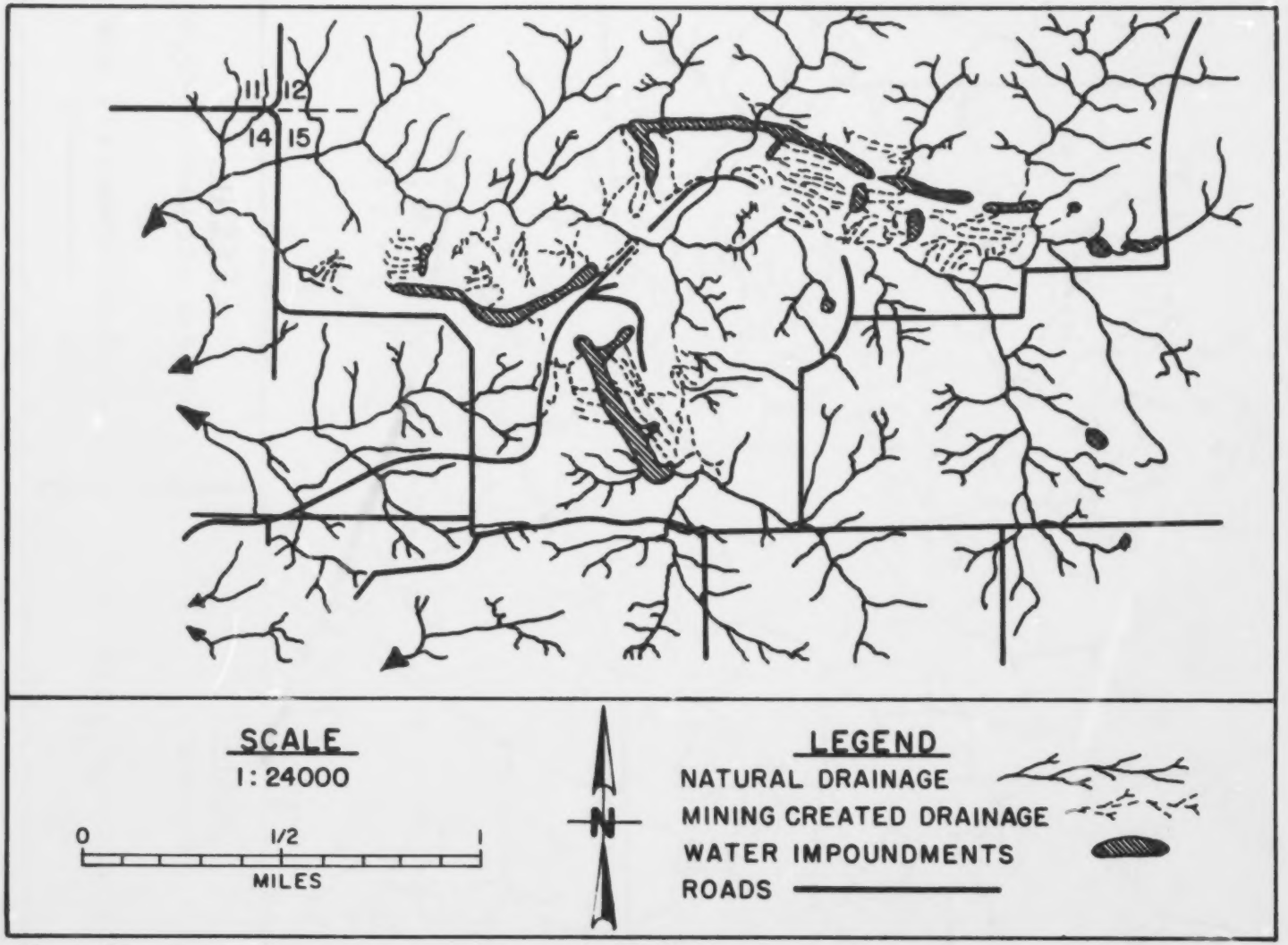


Figure 26. Post-mining drainage patterns of Strip Mine 1, Boone County, Missouri.

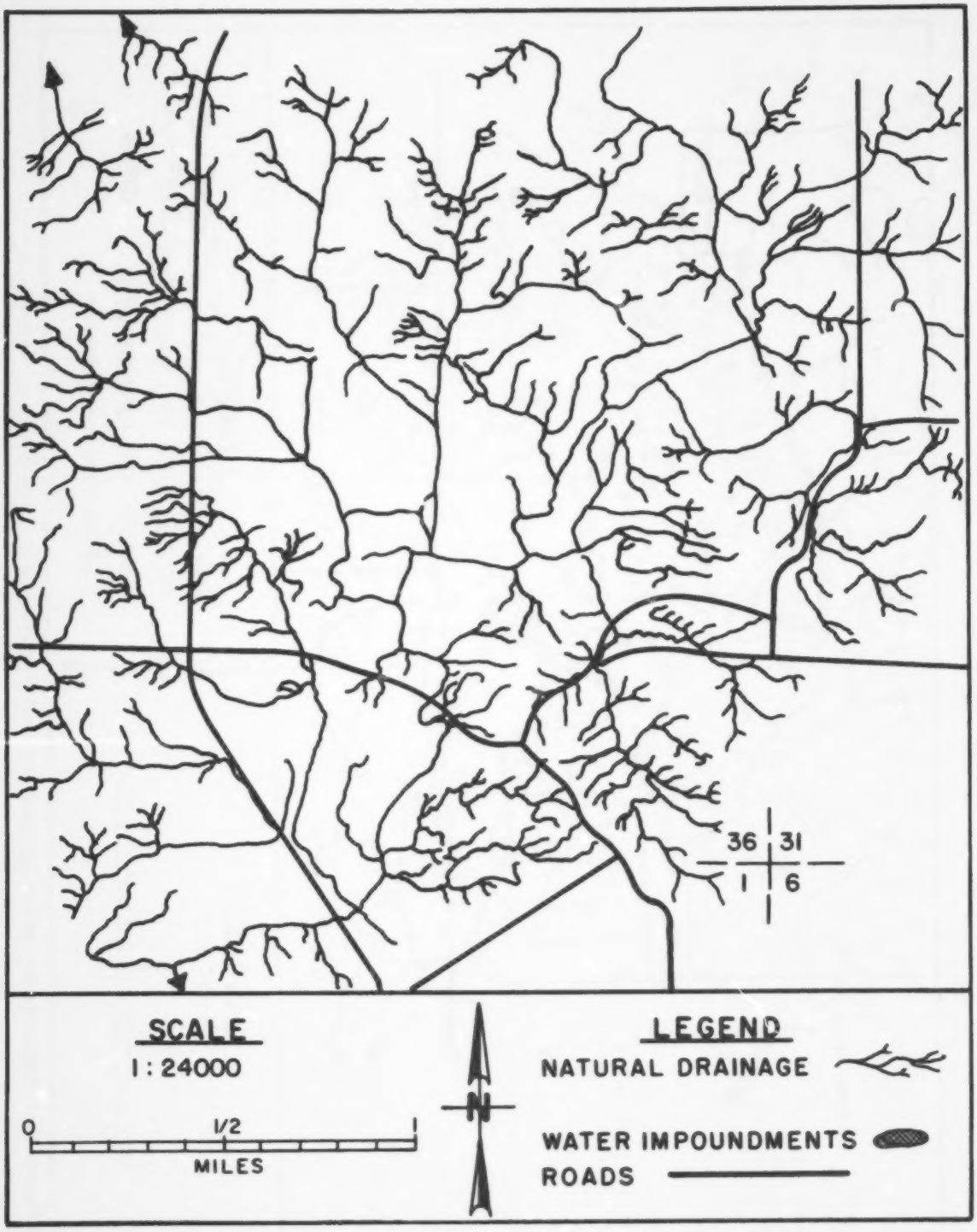


Figure 27. Pre-mining drainage patterns of Strip Mine 2, Randolph County, Missouri.

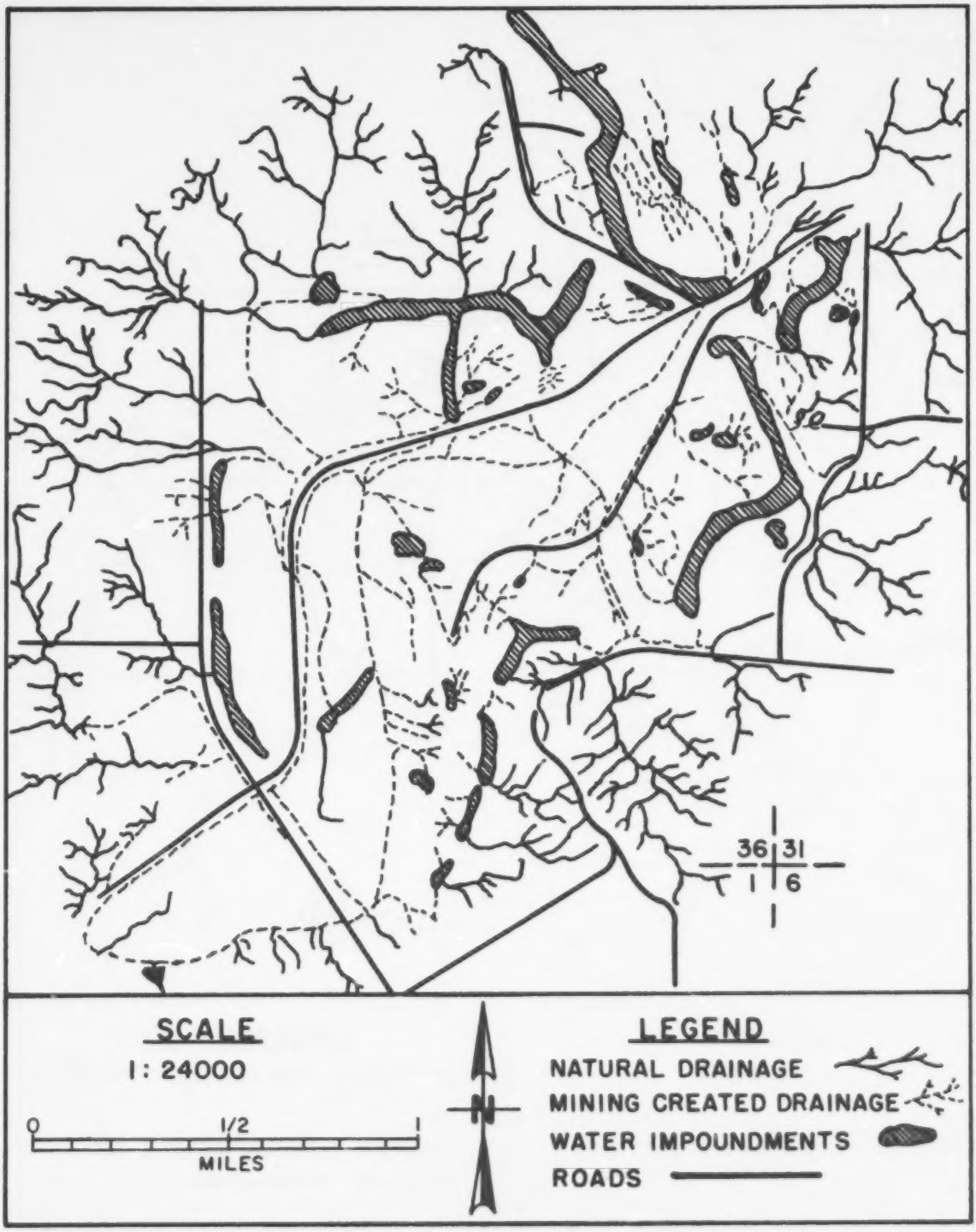


Figure 28. Post-mining drainage patterns of Strip Mine 2, Randolph County, Missouri.

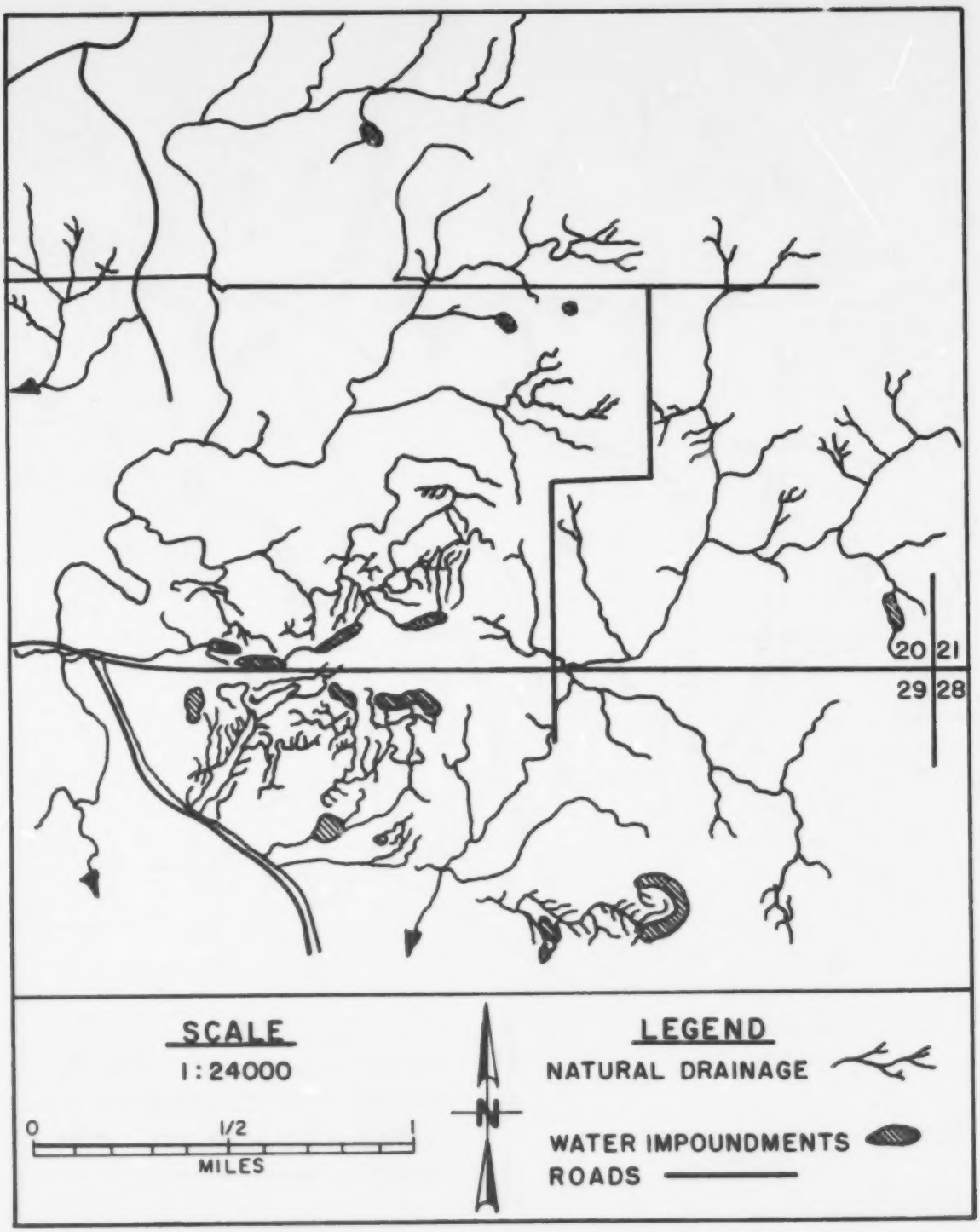


Figure 29. Drainage map showing early (pre-1950) mining plus natural drainage patterns for Strip Mine 3, Macon County, Missouri.

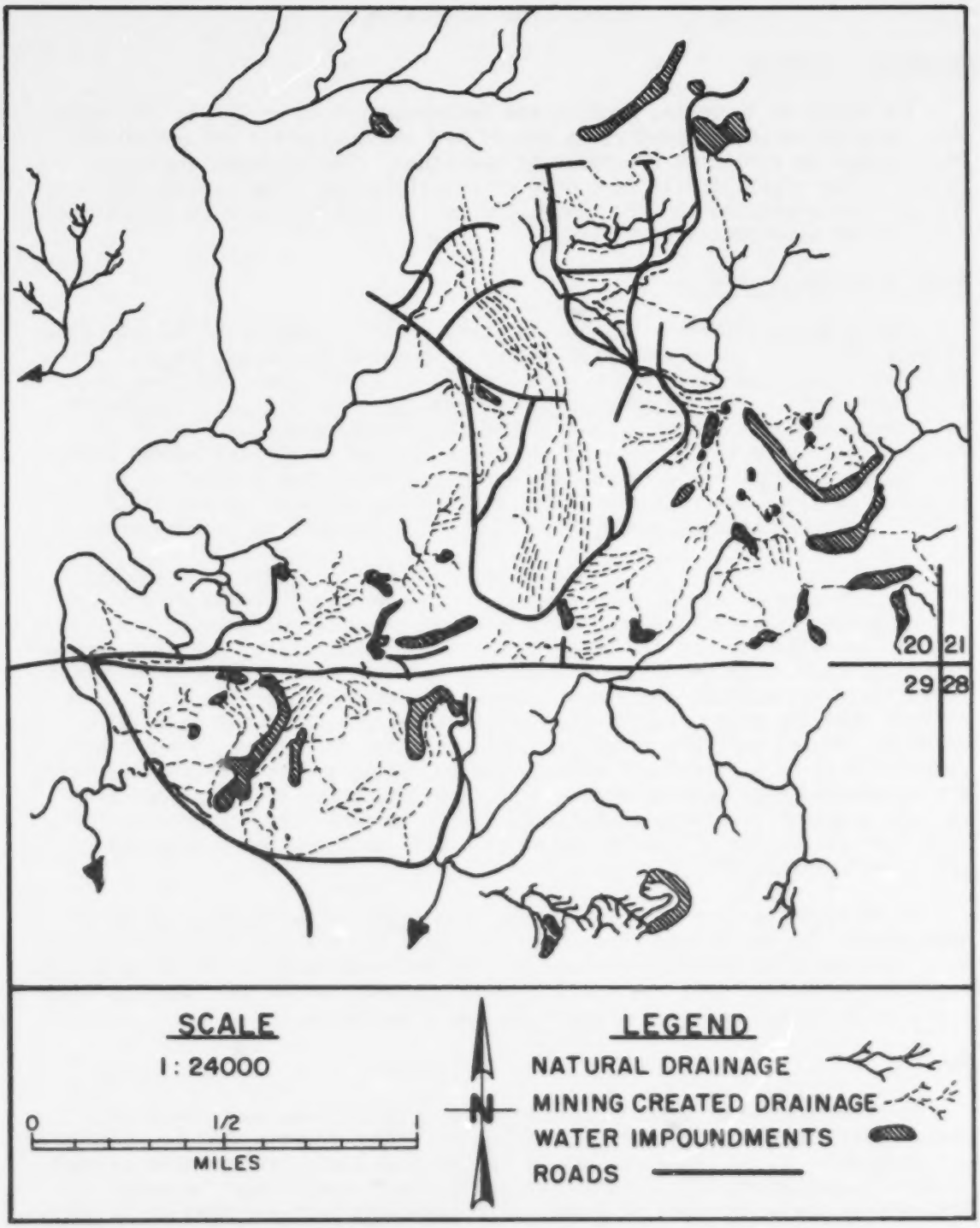


Figure 30. Post-mining drainage patterns of Strip Mine 3, Macon County, Missouri.

RESULTS AND DISCUSSION

Accuracy Standards

The study of drainage, erosion and sedimentation is certainly not exact. Most relationships for predicting runoff and sediment yield are empirical and subject to variation by orders of magnitude. The study of drainage patterns has traditionally been even more qualitative. The results and discussions presented in this report are mostly qualitative with some suggestions based upon promising theory.

Mined Land Landscaping

When a natural terrain surface is strip mined, an entirely new landscape is exposed to the hydrologic cycle. As can be observed on any natural or man-made slope, subaerial erosion constantly works to level the landscape to a base level. Theory and observation suggest that precipitation runoff will concentrate in drainage channels and that these channels will erode headward until the entire surface slope contains an integrated random pattern of channels. After the pattern has been established, the channels will down-cut and tend to erode all of the material lying above elevation of the bed of the trunk stream toward which runoff and sediment is concentrated.

When natural terrain is disturbed by strip mining, the entire surface will be out of equilibrium with respect to the surrounding natural drainage. The disturbed area will utimately reach equilibrium through erosion and sedimentation whether or not the land is reclaimed. The central question should be how to accelerate the state of equilibrium with practical and economically justifiable reclamation practices. Current reclamation practice seems to dictate that the mined area be made as smooth as possible with vegetative cover as soon as possible. Unfortunately, natural terrain which might be considered to be in erosional equilibrium is seldom smooth. Natural terrains are sculptured with concave drainage profiles and concave side slopes and contain numerous branching tributaries. Such surface features provide for efficient collection of runoff and provide soil moisture for vegetative growth for minimum erosion.

It is proposed that disturbed mined land ought to be regraded so as to approximate the sculptured surface of a natural terrain with numerous branching, randomly oriented channels and concave drainage profiles and side slopes. Resulting efficient drainage would benefit revegetation in that surface water would be disturbed more evenly over the reclaimed surface.

Methods

In order to create a sculptured surface with drainage positioned in a natural way, three characteristics of the reclaimed terrain must be calculated or estimated. First, some measure of the largest sized surface area allowed to contribute runoff to a single drainage channel segment must be made. Theoretical investigations of watershed properties* indicate that it is possible to calculate the least size area from which runoff will erode a drainage channel.

*Unpublished Research, Melvin Schaefer, Graduate Instructor, Univ. of Mo.-Rolla 1977.

The equation relating the smallest surface area requiring a drainageway (0th order watershed area) to properties of the terrain is as follows:

Equation 1 $$\frac{1}{A_o} = \left(\frac{2748300}{C_1}\right) \frac{n}{T_s^{13/6}} (i - \Phi) \bar{S}_B^{5/3}$$

where: A_o = 0th order watershed $(mi)^2$ (Least Size Area)

C_1 = Constant of a parabolic stream X-sect

n = Manning's n

T_s = Erosional resistance of soil $\left(\frac{lb}{ft^2}\right)$

$i-\Phi$ = Runoff rate $\left(\frac{inch}{hr}\right)$

$\bar{S}_B$ = Average hillside slope in basin $\left(\frac{feet}{feet}\right)$

An analysis of the parameters in the given equation yields the information found in Table 14.

TABLE 14. RELATIONSHIP OF 0th ORDER WATERSHED AREA AND DRAINAGE DENSITY TO WATERSHED PARAMETERS

Parameter Trend	A_o Trend	Drainage Density
T_s decreases	decreases	increases
$\bar{S}_B$ increases	decreases	increases
n increases	decreases	increases

A second characteristic of terrain necessary for designing efficient drainage is that of drainage density (length of channel per unit area). Shaefer established a relationship between the previously defined least size area and drainage density using the Law of Stream Areas as indicated in Equation 2:

Equation 2 $$\frac{1}{A_o} = D_d \left(\frac{Ra}{\bar{L}_1}\right)$$ where

A_o = Previously defined

D_d = Drainage density $\left(\frac{\Sigma \text{ stream lengths}}{A}\right)$

R_a = ratio of A_1 (area contributing runoff to 1st order streams) to A_o

$\bar{L}_1$ = Average length of first order stream segments (receiving runoff from A_1 areas)

When Equation 2 is substituted in Equation 1, the resulting Equation 3 provides a way in which to calculate a theoretical drainage density for a given set of terrain properties.

$$\underline{\text{Equation 3}} \quad D_d = \left(\frac{2748300\ \bar{L}_1}{R^{Ra}\ C_1}\right) \quad \left(\frac{n}{T_s^{13/6}}\right) \quad (i-\Phi)\ \bar{S}_B^{5/3}$$

The third set of terrain characteristics needed for drainage design includes drainage orientation and channel and side-hill slopes. As stated previously, natural drainage systems free of external control are randomly oriented in a branching, dendritic pattern. Such a pattern could be layed out by observation or by using statistical procedures called a "random walk." However, the random pattern naturally facilitates the movement of sediment through the drainage system and often is modified by man so as to cause sedimentation to occur within a predictable location. Optimum drainage channel and hill-side slopes are not easily predicted. Slopes formed of loose, coarse grained material may lie at the material angle of repose (30°- 35°) whereas slopes formed of fine grained clayey material may range from 1°to 15°. Drainage design might be facilitated by using slope values exhibited by natural terrains in the local area.

Study Site Observations

An evaluation of drainage patterns, drainage density, drainage orientation and slope geometry was made by comparing pre-mined and post-mined conditions with hydrologic conditions hypothesized to be the most efficient to carry runoff with a minimum of erosion.

The drainage density values indicated in Table 14 show that the youngest site (Strip Mine 2) exhibited a lower drainage density upon reclamation than the site had prior to mining. Theory would indicate, however, that mining and reclamation should decrease soil shear strength, increase surface roughness (Manning's n) and possibly increase average side slopes. All of these trends require a great increase in drainage density for efficient runoff as seen in Equation 1 and Table 15. The conclusion reached is that erosion will occur until the necessary drainage pattern and density has been constructed.

Strip Mine 1 contains sub-units which tend to confirm that erosion will continue until an efficient drainage system has developed. The post-law reclaimed site, older than Strip Mine 2, exhibits a slightly greater drainage density than the site exhibited prior to mining. The much older pre-law site exhibits a much greater drainage density. As a dense drainage pattern is created, the sediment yield due to erosion will be great.

In addition to the potential for erosion created by unnaturally low drainage densities left as a result of reclamation, the shape of reclaimed slopes also creates the potential for erosion. The shape of hills and ridges was more variable in those areas after mining with terrain shape dependent upon the method of reclamation. Pre-law sites had higher relief with convex to uniform slopes. Post-law sites exhibited less relief with complex to uniform long uninterrupted slopes. In all cases, post-mined conditions deviated significantly from natural slope shapes as they existed prior to mining.

The slope geometry could be an important aspect of controlling erosion on mined lands. Hydrologic studies consistently indicate that a "graded stream" having a concave profile is the most efficient for transport of runoff with minimum erosion. The same is true for hill and ridge side slopes. In the process of reclamation, the terrain is usually left with convex sloping surfaces. The soil that exists between the final grade and some lower concave sloping surface is bound to be eroded away during the process of drainage development.

Reorientation of drainage channels transverse to the dendritic pattern tends to trap sediment resulting from the previously described phenomena. In terms of erosion, therefore, lakes created by highwalls transverse to the natural flow of drainage act as sedimentation ponds. Such situations probably tend to impede erosion and at least ensure that sedimentation will occur within the mine site.

Applications

Although none of the concepts presented herein have been evaluated for economic praticality or for that matter by field testing, there is strong evidence that reclamation could be improved by making reclaimed surfaces more nearly the shape of natural surfaces. Initial grading for creation of concave slope profiles and well-defined randomly oriented channels could reduce the potential for natural erosion to carve these shapes. Also, the drainage on previously reclaimed mine areas could be modified so as to induce more randomness in drainage as well as concave slopes and thus reduce natural erosion. Further study might lead to tested values for desired terrain characteristics, but at present a sculptured terrain as previously described would have to be designed using a combination of theoretical, and estimated numbers as well as a great deal of artistic interpretation and inference.

The following outlines a series of steps which, if undertaken, would tend to cause reclaimed land to be more natural in shape and consequently less prone to severe initial erosion:

A. Runoff Area Design - Some estimate of A_0 (least size area or 0th order watershed) must be made. A_0 defines the smallest area high in the drainage network, the runoff from which supports the creation of a drainage channel. Figure 31 illustrates the concept of A_0. In nature A_0 would tend to decrease until equilibrium is reached. A reasonable first approximation for A_0 would be values measured from

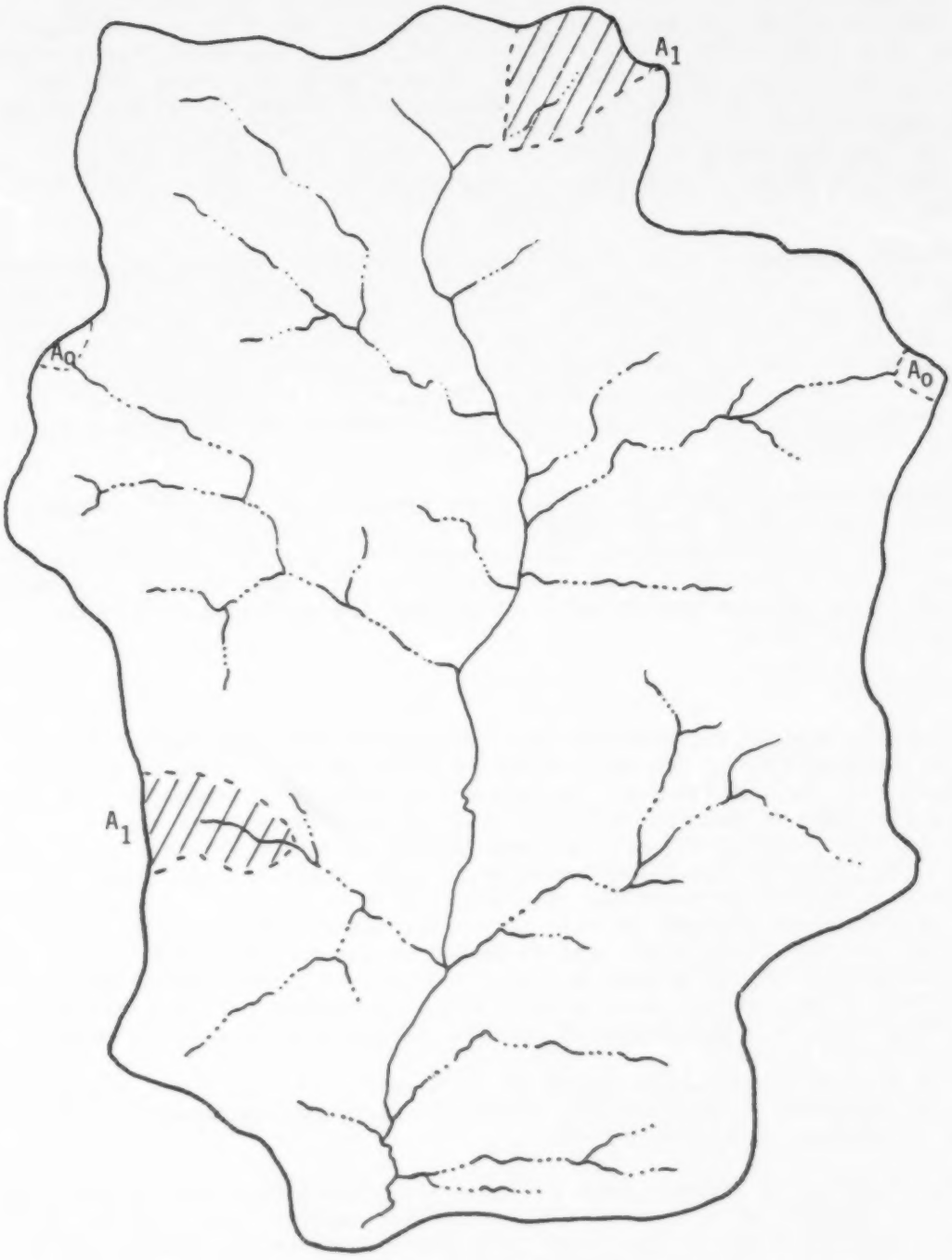


Figure 31. A random drainage pattern with A_o and A_1 defined by sub-unit drainage divides.

maps or airphotos of the pre-mine site. Values for some Central Missouri watersheds range from 0.4 to 0.6 acres.

Although mining and subsequent reclamation would tend to reduce optimum A_o values as indicated in Table 15, the pre-mine values would at least provide a starting point. A reclamation specialist could implement this factor by making sure that no surface area larger than A_o exists without being drained by a well-defined channel.

It will be noted that new erosion channels formed on reclaimed land tend to reduce the magnitude of the A_o parameter. A reclamation specialist could modify channeling after inspection of such an area to reduce the size of A_o sub-units and thus alleviate erosion.

Another approach would be that of estimating A_1 from maps or airphotos. A_1, illustrated in Figure 31, represents the area contributing runoff to the first order tributaries (the smallest channels highest in the drainage hierarchy). Values of A_1 in Randolph County Missouri as measured from several watersheds varied from 2.0 to 3.85 acres.

A third approach toward determining minimum sized surface areas allowed to contribute runoff to a channel would involve calculation using Equation 1. The dependent variables in Equation 1 could be measured or estimated from similar terrain or measured in a field test for use in similar reclaimed areas. In natural Mid-Missouri watersheds C_1 = 12-13, N = 1.5-2, τ_s = 0.4-0.6, ($i-\phi$) = 1.2 ± and $\overline{S}_B$ = 2° - 16°. Of all the variables, τ_s is most significant in causing change in A_o. Equation 1 would be most helpful when used in conjunction with a field test aimed at collecting values for extrapolation to similar areas.

B. Drainage Density - Design of drainage density should include a drainage plan with enough channel length to yield the appropriate drainage density for the site. The drainage layout could best be sketched in a natural appearing random (dendritic) branching pattern. A first approximation to the required drainage density could be measured from pre-mine maps and photos and then increased somewhat for effects of disruption. A second approach would be that of drainage density calculation using Equation 3. As with Equation 1, dependent variable values could be estimated or measured from field tests. In the case of natural Mid-Missouri watersheds R_a may typically vary from 3.5 - 4.0.

Drainage channels should be constructed to resemble natural channels. All channels should have a parabolic cross-section. However, the depth of channel should grade from shallow (0.5 feet±) at the head-end to several feet depth for trunk collector channels. Top bank widths should range from perhaps 12 feet wide for small tributaries to broader channels in the trunk streams. The gradient of the channels should be steepest at the head-end with flattening toward the mouth of the primary trunk stream.

C. Slope Profiles - In the process of creating drainage channels some effort should be taken to sculpture the land into concave shapes where possible. Slopes in natural terrains in Central Missouri may vary from 2° to perhaps 16° with shapes approximating concave or complex cross-sections. Similar shapes within watershed sub-unit would tend to reduce severe initial erosion. In some measured sites in Central Missouri, the largest slope length contributing runoff to a channel in natural terrain was about 150 feet. A value somewhat less than this should be used in a reclaimed site.

INFORMATION PROGRAM

by

Dr. Chris J. Johannsen 1/

The investigators of this project have presented the research results to the Missouri Land Reclamation Commission on a regular basis. The Commission members were especially encouraged by the computer analysis techniques for inventorying and estimating the area of vegetation, bare soil and water on mined lands. The Land Reclamation staff was encouraged to obtain color infrared photography over all mined areas in Missouri. A cooperative agreement was signed with the Environmental Protection Agency to acquire high altitude color infrared photography (1:48,000). The photography was flown in July, 1978. Arrangements have been made with the Bio-Engineering Programs, University of Missouri-Columbia to analyze the photography by computer and provide maps and data of vegetation, soil and water areas by mining location.

Meetings have been held with Area Agricultural and Area Community Development Extension Specialists located near mined lands. Concerns were expressed by the specialists for information to provide land owners regarding lease arrangements, reclamation procedures and total community impact. A conference on "Coal and You" was held in the Green Hills Area of North Central Missouri which addressed some of these concerns. Numerous requests have been received from land owners for additional information.

A conference on "Remote Sensing in the Future of Missouri Mining" was held in March, 1977, for members of the Missouri Mining Industry Council. This conference was the result of discussions with industry members and the Land Reclamation Commission. A workshop has been requested by industry on prime farmland. This has become a major concern since the passage of the Surface Mining Control and Reclamation Act of 1977. Coal companies are currently sending their preliminary reclamation plans to the investigators for comment before submitting them to the Land Reclamation Staff.

The requests for copies of papers, reports and results from individuals has been steadily increasing since the initiation of this grant. Land owners and coal companies have requested assistance and advice on such topics as vegetation establishment, erosion and drainage problems, and alternative uses of mined lands. Approximately three newspaper articles, six radio tapes and one television presentation have been made during the past two years which involved results from this project.

1/Professor of Agronomy, University of Missouri-Columbia

REFERENCES

Brickner, T., 1977, Some Factors Affecting Erosion. Unpublished research report. University of Missouri-Rolla, Rolla, Missouri 65401

Carrel, J.E., J.E. DeMott, and D.M. Zight, 1977, Surface Mine Revegetation: Area Metering of Ground Cover. Fifth Symposium on Surface Mining and Reclamation, Louisville, Kentucky.

Carrel, J.E., C.J. Johannsen, T.W. Barney, and W. McFarland, 1978a, Measurements of Vegetative Cover In Surface Mines. Twelfth Symposium of Remote Sensing of Environment, Manila Phillipines.

Carrel, J.E., K. Wieder, V. Leftwich, S. Weems, C.L. Kucera, L. Bouchard and M. Game, 1978b, Strip Mine Reclamation: Production and Decomposition of Plant Litter. Proceedings International Congress for Energy and Eco Systems. University of North Dakota, Grand Forks, North Dakota.

Curtis, J.T. and G. Cottham, 1956, Plant Ecology Workbook, Laboratory, Field and Reference Manual. Burgess Publishing Company, Minneapolis, Minnesota.

Robertson, C.E., 1971, Evaluation of Missouri's Coal Resources. Missouri Geological Survey and Water Resources, Rolla, Missouri 65401, RI No. 48.

Young, J.A., 1978, Missouri's Coal Mining and the Environment. 208 Water Quality Management Guide (WQG-5), University of Missouri, Columbia.